THE PRINCIPLES

OF

VENTILATION AND HEATING

AND THEIR

PRACTICAL APPLICATION.

BY

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PREFACE.

During the years 1880–'81–'82, the writer contributed to the Sanitary Engineer a series of papers entitled "Letters to a Young Architect on Ventilation and Heating." These letters were originally prepared to meet current demands, and to answer questions sent to the journal, and had, therefore, no special connection with each other. The following work contains the substance of these papers, the whole being re-arranged and in part re-written, and new matter and illustrations being added. It is not intended to be a systematic manual on ventilation and heating for the instruction of the skilled architect or engineer, but rather to present the general principles which should guide one in judging of the merits of various systems of, and appliances for, ventilation, more especially as applied to large public buildings, with some illustrations of their practical application, and this has been done as far as possible without the use of technical expressions, or of any but the simplest mathematical formulæ.

The number of queries from architects, physicians and others, which appear from time to time on this subject, is sufficiently great to warrant the belief that there is a demand for an explanatory work on the subject, and it is hoped that this volume may serve to meet the want.

Washington, D. C.,
May 1st, 1884.

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INTRODUCTORY — EXPENSE OF VENTILATION — DIFFERENCE BETWEEN "PERFECT" AND ORDINARY VENTILATION—RELATIONS OF CARBONIC ACID TO THE SUBJECT — METHODS OF TESTING VENTILATION.

THE immediate cause for the following pages was the receipt of a request for "some plain, practical directions as to the best methods of arranging the ventilation of a building, to be given, as far as possible, in the form of specifications which can be easily understood by an intelligent builder, and not in the form of abstruse mathematical formulæ." The author of this request went on to state that he had "looked over several books on the subject, but had found them chiefly made up of long-winded scientific speculations about the physics of gases, the composition of the atmosphere, units of heat, etc., and could not obtain from them a simple statement as to how to ventilate a large school-house," which seemed to be the problem in which he was immediately interested.

This request reminds me of the demand for medical education made by some young men I have met. They do not wish to take the trouble to learn anatomy and physiology; they want to learn how to cure the ordinary diseases of the country—typhoid fever, inflammation of the lungs, etc.—and they want this information neatly packed and labeled in the form of recipes or formulas contained in a vest-pocket manual, which can be consulted as occasion demands.

There is no such royal road to knowledge as these demands presuppose. One must learn the alphabet before one can become a schoolmaster.

The arrangement of the plans of a large building, so as to secure satisfactory results in its heating and ventilation, is not such a simple matter as this demand would indicate. It cannot be done by following a formula.

But while it is impossible to comply with the request of my correspondent in the precise and concise manner which he wished, it is perhaps possible, and if so it seems desirable, to present the subject in such a way that architects will appreciate its importance in their work—and understand its difficulties, and the general principles which should guide them in endeavoring to overcome these difficulties—more fully than many of them seem to do at present.

Every one who has occasion to examine the subject discovers that it is difficult to secure good ventilation throughout a building, but very few know what the principal difficulty is. Many persons seem to suppose that it depends upon some properties of gases as yet unknown, or upon some mysteries, connected with the fact that heat is a mode of motion of the molecules of matter, which can only be expressed in complicated mathematical formulæ.

The essential difficulty, however, which architects and engineers, in the exercise of their profession, will find most prominent, is that of cost. If the question of expense be entirely set aside, ventilation becomes a comparatively simple matter. The object to be attained can be defined with sufficient precision, and the resources of modern engineering are ample to attain this object in almost any building that can be planned; but good ventilation is expensive, both as to the mode of construction and the apparatus which it demands, and as to its maintenance after the necessary conditions have been provided.

The first problems which the architect has to solve for each building which he plans or constructs are not so much how to arrange flues, fireplaces, furnaces, etc., so as to secure good ventilation, as the following, viz.: (1) How much money can be afforded to secure good ventilation? and (2) which of several methods should be employed to effect this, taking into consideration the amount of funds available and the character and location of the building? The answers to these two problems will seldom or never be the same for any two buildings having different owners, and the reader can therefore, perhaps, see the absurdity of a request for "the best methods of arranging the ventilation in a building."

The first problem above alluded to is one to which I hope that in future more attention will be given than is usually bestowed upon it by those whose business it is to plan comfortable and healthy dwellings.

I do not mean by this that when a gentleman comes to an architect for a plan for a house, giving the usual data as to location, dimensions, and proposed cost, that he is to be asked as to how much of this cost he is willing to devote to ventilation. It is the business of the architect to tell him that, and to be careful, from the very beginning, that, even in his first rough-sketch plans, satisfactory arrangements for ventilation are included. It is his duty also to see that, after the various additions to the plan which will be made at the suggestion of the owner's wife and several of his friends on whose taste he relies, have increased the cost above what he had intended, he does not, in the spasm of economy and retrenchment which will attack him, make a reduction in some point which will affect the ventilation rather than on some of the ornamental work outside.

The connection of the heating of a house with its ventilation is, of course, inseparable. Now, many persons will cheerfully expend from fifteen to twenty thousand dollars in building a house, putting from three to five thousand dollars into ornamental stonework and cornices, who would not dream of spending from a thousand to fifteen hundred dollars for the necessary hot water or low pressure steam apparatus to keep this same house thoroughly and comfortably warmed and well ventilated. If, however, at the very commencement, the desirability of this is pointed out by the architect, as he should do in his capacity as expert professional adviser, he will in almost every case find that his client will accept his advice just as he will that for a proper arrangement of the drains and plumbing work. By taking this course the architect will find his clients much better satisfied with their houses and with himself than if he defers to their ignorance in these matters.

When it comes to the planning of such a building as a public school, I consider it to be the duty of the architect not only to advise, but to insist upon proper arrangements for heating, ventilation, drainage and plumbing ; and if it is his misfortune to have to deal in this subject with ignorant committeemen, who, with a limited appropriation for the purpose, persist in omitting, for the sake of cheapness, some of these points in construction which are essential for keeping the building in proper sanitary condition, it will be his duty to decline to have anything to do with the matter rather than suffer himself to be used as a tool to execute work which he knows will be dangerous to the health and life of the children of his fellow-citizens.

First of all, then, keep in mind this axiom, which applies especially to the large cities in our Northern States, viz.: In this climate it is impossible to have at the same time good ventilation, sufficient heating, and cheapness.

The fact that good ventilation is expensive is not so well recognized as it should be, for the reason that much of our literature on the subject is furnished by English authors, who write with reference to the climate of England. This climate is very different from our own, being much more uniform. The most important peculiarity, however, of the English climate is due to the high proportion of moisture contained in the air, which permits of the use of lower temperatures in warming than can be used here.

In this country, rooms must be kept at a temperature of from 68° to 70° Fahr., to insure the comfort of the occupants, while in England 60° Fahr.

seems to be the recognized standard. Open fire-places and grates can therefore be used there more extensively than here, and in arranging apparatus for heating by indirect radiation, it is necessary to provide more heating surface than is called for by the specifications of English engineers. This is a fact which must be constantly borne in mind in reading the books of Edwards, Hood, or other English writers on this subject, and it will be found well presented and strongly insisted on in a paper by Mr. Robert Briggs, in the January and February numbers of the *Journal of the Franklin Institute* for 1878, entitled, "On the Relation of Moisture in the Air to Health and Comfort."

What is it that we desire to effect by ventilation? and how may we define "good ventilation," or know whether it has been secured in any given building? Ventilation is ordinarily defined to be the removal of foul and the introduction of fresh air, but this gives a very insufficient idea of what is meant by the word. Ventilation is securing a change of air. It may be required for the purpose of removing moisture, as in the drying-rooms of a cotton factory, or in a cellar, or to keep the air of rooms fit for respiration. In the great majority of cases it includes the idea of a thorough mixing of pure air with impure air, in order that the latter may be diluted to a certain standard.

Perfect ventilation can be said to have been secured in an inhabited room only when any and every person in that room takes into his lungs at each respiration air of the same composition as that surrounding the building, and no part of which has recently been in his own lungs or of those of his neighbors, or which consists of products of combustion generated in the building, while at the same time he feels no currents or draughts of air, and is perfectly comfortable as regards temperature, being neither too hot nor too cold. Very rarely, indeed, can such perfect ventilation be secured if the number of persons in the room exceeds two or three; in fact, I have never seen but three or four attempts in this direction. One of these was in the house of the late Mr. Thomas Winans, of Baltimore, where the floors were perforated uniformly all over the room, as was done by Dr. Reid for the British House of Commons, thus making the floor a gigantic register or grating through which the fresh incoming air, having been previously warmed and moistened in mixing chambers below, is to stream steadily upward at a uniform velocity sufficient to remove all the products of respiration or of combustion as rapidly as formed. It requires even more than this to secure the perfect comfort as regards temperature above alluded to, but this will be explained when I come to speak of the heating and ventilation of large assembly halls. The amount of air required to secure this perfect ventilation is very great. Take, for instance, a room twelve feet square, and suppose that the air in it is to move uniformly upward at the rate of six inches per second. This is equivalent to an air supply of 72 feet per second. Theoretically, it is true that, if the air moves regularly and steadily upward at all points in the room at the rate of even one inch per second it might be sufficient—but practically, at least six times this velocity is required to overcome disturbances caused by opening doors, etc.

Probably this statement of air supply required gives no definite idea as to its cost, and it may be more fully understood by considering that it would require at least thirty times as much coal to heat a room thus supplied as would be used for heating a room of the same size having only the ordinary heating and ventilating arrangements.

What would be considered by all sanitarians as good ventilation would not require nearly so much air as this. Good, ordinary ventilation is to be secured by keeping the vitiated air constantly diluted to a certain standard. It does not attempt to secure in a building or room air as pure as that outside, but only air which shall contain but a certain proportion of impurity—for all the air with which our ventilating appliances are to deal will contain impurities. Some of these impurities are more dangerous than others, and are less affected by this process of dilution. Offensive or poisonous gases of all kinds, such as sulphuretted hydrogen or carbonic oxide, can be diluted by fresh air, just as solutions of arsenic or strychnine can be by pure water, until a mouthful of such diluted air or fluid is neither specially hurtful or unpleasant. The dangerous impurity in some air, such as that in a hospital ward for contagious diseases, or in air from a sewer or a collection of filth of any kind, is not a gas, and does not possess any very marked or unpleasant odor. It consists of very minute particles of organic matter, which are capable of producing disease when introduced in the living human body, and some of which are capable of growth and multiplication under certain circumstances. The process of diluting foul air which contains such particles—or particulate contagia, as they are sometimes called—cannot render such air certainly harmless any more than by diluting vaccine virus we can make sure that none of the fluid will give a successful vaccination. No amount of fresh air will dilute one of these particles, and a single one may produce the disease. All that dilution will certainly effect is, that in a certain air space there shall be but one or two such particles instead of a hundred, and thus the probability of an infection by an exposure for a limited period may be much diminished. It is also probable, however, that for the great majority of the disease germs, exposure to and agitation in large quantities of fresh air, especially if this contains ozone, will destroy or greatly impair their vitality and powers of doing harm.

In view of this fact, it will perhaps occur to the reader that one of the first things to be done in arranging the ventilation of a building is to prevent, as far as possible, the admission into it of these particulate contagia—these mysterious germs of disease which are so hard to dispose of if they have once gained entrance—and that it is therefore worth while to examine closely the details of the plumber's work in connection with this question.

In the great majority of buildings it will be considered desirable to arrange the ventilation with reference only to the ordinary impurities of air in the inhabited rooms. Now, what are these impurities? Possibly the reader may smile complacently at this question, thinking, "Well, I know that, at all events: it is carbonic acid, of course," but if he does, he is mistaken.

Whenever a man takes the ground that carbonic acid is the special impurity that is to be provided for, and asserts that, as it is heavier than ordinary air, therefore it sinks to the floor, he demonstrates that he is a person who may be a very estimable gentleman, but whose opinions about ventilation should be received with very great distrust.

Yet it is a fact that if there is any one thing that the average amateur ventilator is more sure of than another, it is that carbonic acid gas is the principal evil to be guarded against.

When he writes his first paper on the subject he will enlarge upon the "deadly nature of this subtle poison," and will refer to the Black Hole of Calcutta as proving its powers. He will also, in the same paper, announce his discovery that "this deadly gas is heavy and collects near the floor," and that therefore special arrangements should be made to remove it from that point. He may also indulge in some speculations as to the well-known great mortality among children under five years of age being due to the fact that they are so short that their faces are constantly bathed in this pool of heavy gas, and he will allude in a familiar manner to the Grotto del Cane.

If he happens to be an architect, he may even proceed to put his theory to a practical test, for I have seen, in large and costly buildings, holes carefully provided at the level of the floor to allow this terrible carbonic acid gas to run off.

Now, all this is nonsense; and until a person knows enough of the physics of gases in general, and of carbonic acid gas in particular, to be sure that it *is* nonsense, and to be able to demonstrate *why* it is so, it is useless to discuss ventilation problems with him. Let us note a few of the characteristics of gases in general, and of the air and carbonic acid in particular, which are of especial interest in this connection.

The atmosphere, which surrounds us like an ocean, and at the bottom of which we construct our buildings, is composed of three gases, viz., oxygen, nitrogen, and carbonic acid. These gases are mixed in varying proportions, the amount of carbonic acid being very small. The mixture is a very perfect one, although these gases have each a different weight for the same bulk, and this uniformity of mixture depends upon what is known as the law of the diffusion of gases. Every gas expands freely and rapidly into a space occupied by another gas, much as if this space were a vacuum. If we take a tall glass jar and introduce at the bottom some pure carbonic acid gas, leaving ordinary atmospheric air above, and close the jar, we shall find in a short time that the carbonic acid has diffused upward and the air downward, until the composition of the mixture is exactly the same in all parts. Observe, also, that this mixture will never separate again, unless we compel such separation by placing it in some substance which will combine with or absorb one of the gases and not the others.

In our ocean of air, the proportion of carbonic acid to the other gases, is substantially the same at a point ten miles above the earth that it is on the sea level, just as the proportion of salt in the ocean is about the same at one foot below the surface that it is at one mile depth.

The same is the case with an inhabited room; the proportion of carbonic acid at the floor will be about the same as, and in some cases even less than at the ceiling, depending upon the currents in the room, and upon the fact that the principal sources by which the proportion of this gas is increased in a room, viz., respiration and lights, produce it usually in a mixture at a higher temperature than that of the room, and weighing less than the same bulk of ordinary air. For this reason it rises, and by the time it has cooled it is thoroughly diffused through and mixed with the rest of the air of the room, from which, as just explained, it will not separate.

If carbonic acid is produced rapidly in a space enclosed on all sides except at the top—as, for instance, in a well or the shaft of a mine, or in a large empty beer or wine vat—it will expel the air and remain at the bottom of the space until diffusion has been accomplished. When in such a case the temperature of the carbonic acid gas is the same as that of the surrounding air, so that no currents are produced, the process of diffusion is slow, and if a slight production of carbonic acid gas be kept up from below, it will remain almost like water in a barrel, as it does in the Grotto del Cane and in the places above referred to. It is only under such circumstances, however, that it is ever necessary to make special provision for getting rid of carbonic acid gas; and it is not probable that the architect will ever have occasion to make any such arrangements for its disposal.

In what would be termed "pure country air," carbonic acid is present in the proportion of about 4 parts in 10,000. In a crowded and confined space, such as the pit of a theatre and in some school-rooms, its proportion has been found to rise to 30, 40, and even 100 parts per 10,000.

Pure carbonic acid gas may be present in air in a proportion as high as 150 parts per 10,000, without producing discomfort or giving any special evidence of its presence, as, for instance, in those establishments where sparkling mineral waters are bottled, or soda fountains are charged, or in vaults where champagne is bottled, in certain rooms in breweries, or in some celebrated baths and health resorts.

It is evident, therefore, that carbonic acid gas—in the proportions in which we find it in our worst ventilated rooms—is not in itself a dangerous impurity; in fact, we have no evidence to show that in such proportions it is even injurious.

What, then, is the importance of this gas in relation to questions of ventilation? and why do sanitarians lay so much stress upon the results of chemical tests of air with reference to this substance, and on what may seem very small variations in the proportions in which it is present?

It is because carbonic acid is usually found in very bad company, and that variations in its amount to the extent of three or four parts in ten thousand indicate corresponding variations in the amount of those gases, vapors, and suspended particles which are really offensive and dangerous, and also because we have tests by which we can, with comparative ease and certainty, determine the variations in the carbonic acid, while we have no such tests of recognized practical utility for the really dangerous impurities.

As a matter of convenience, therefore, we measure the carbonic acid, and thus get a measure of the extent to which ventilation is being effected. Of course, we must make sure that the circumstances of the case present nothing unusual, since, on the one hand, carbonic acid may be present in great excess—as in a soda-fountain-charging room—without indicating great impurity; and, on the other, it is possible that the air of a room may be very dangerous, from suspended organic particles, and yet have carbonic acid present in merely normal amount. This will appear more clearly when we come to consider the ventilation of hospitals for infectious diseases.

But while the quantity of carbonic acid which is contained in some of our worst ventilated rooms is not injurious to human life, the amount of this gas present is nevertheless of very great importance in relation to ventilation, and very small variations in it—even so little as one ten-thousandth part—are often very significant, because we measure by it the quantity of dangerous impurities present, since we cannot conveniently measure these impurities themselves.

In most treatises on ventilation we are told that the best test for the presence of an undue amount of impurity in the air is the sense of smell. When a person goes from the fresh outer air into an inhabited room, and does not perceive any special odor, it is usually safe to assert that that room is well ventilated. But while this is true, it is necessary to have some other test which will be independent of individual peculiarities, and the results of which can be demonstrated to others. The man who has a patent sanitary stove, or an automatic ventilator, will rarely find any disagreeable odor in a room fitted with his appliances. The carbonic acid test for foul air depends upon the fact that when, as the product of respiration, the proportion of carbonic acid in a room increases from the normal amount of 4 parts in 10,000 to between 6 and 7 parts in 10,000, a faint, musty, unpleasant odor is usually perceptible to one entering from the fresh air. If the proportion reaches 8 parts the room is said to be close.

To secure entirely satisfactory ventilation which will prevent this odor, the proportion of carbonic acid derived from respiration, or what is sometimes called the "carbonic impurity," should never exceed 2, or, at the utmost, 3 parts in 10,000 of the air in a room; that is, if the proportion in the fresh air be 4, that in the foul air must not exceed 7. The testing the amount of carbonic acid present is, although a simple operation, one which requires much care and precision throughout. Even in collecting the sample of air for examination, special precautions are required, since if any one has his head too close to the jar, or if several persons gather around to see what is going on, the sample will show too high a proportion of carbonic acid.

For ordinary purposes a convenient method of testing the amount of carbonic acid is the following, for which there will be needed six well-stoppered bottles, containing respectively 450, 350, 300, 250, 200, and 100 cubic centimetres, a glass tube or pipette graduated, to contain exactly 15 cubic centimetres to a given mark, and a bottle of perfectly clear and transparent fresh lime-water. The bottles must be perfectly clean and dry. Having made sure that they are filled with the atmosphere which is to be examined, which can best be done by pumping into them a quantity of this air by means of one of the small handball syringes, which may be procured in any drug store, and taking care that none of your own breath is pumped in, add to the smallest bottle by means of the pipette, 15 cubic centimetres of the lime-water, put in the cork, and shake the bottle. If turbidity appears, the amount of the carbonic acid will be at least 16 parts in 10,000. If no turbidity appears, treat the next-sized bottle, viz., of 200 cubic centimetres, in like manner. Turbidity in this would indicate 12 parts in 10,000. If this remains clear, but turbidity is produced in the 250 cubic centimetre bottle, it marks about 10 in 10,000. The 300 centimetre bottle indicates 8 parts, the 350 7 parts, and the 450 less than 6 parts. To judge of the turbidity, mark a small piece of paper on the inside with a cross in lead pencil, and gum to the side of the bottle on the lower part. When the water becomes turbid the cross will become invisible when looked at through the water. This will enable one to judge roughly of the amount of carbonic acid in the air. For more accurate analysis the processes can best be learned by spending about three hours a day, for three or four days, in a laboratory, working under the directions of a good chemist.* A very simple, compact and convenient piece of apparatus, for the application of the quantitative baryta test, has recently been devised by Mr. Frederick N. Owen, of New York City, and is described in the *Sanitary Engineer* of April 3, 1884.

In this apparatus a solution of phenolphthalein, one of the aniline colors, is used instead of litmus or turmeric, to indicate the precise moment

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* The following is the method of Pettenkoffer, as described by Dr. Parkes : Take a glass jar, holding a gallon or 4½ litres, and fill it with the air to be examined, by means of a bellows, or by filling the vessel with water and allowing it to drain off in the place, the air of which is to be examined. Then add 60 cubic centimetres of clear lime or baryta-water and close the mouth of the jar by a rubber cap or stopper made air tight in other ways, shake it up thoroughly and allow it to stand for six or eight hours. The carbonic acid is absorbed by the lime or baryta, lessening the amount of caustic or free alkali in the fluid.

The causticity of the lime or baryta-water is determined both before and after it has been placed in the vessel, by means of a solution of crystallized oxalic acid (2.25 grammes of the acid to 1 litre of water), 1 C.C. of which exactly neutralizes .001 gramme of lime. The point of neutralization is determined by turmeric paper or by litmus. The number of cubic centimetres of the standard solution of oxalic acid required to neutralize, say, 30 C.C. of the fresh lime-water, equals the amount of lime—that is, between 34 and 41 milligrammes.

After the lime-water has absorbed all the carbonic acid in the jar, 30 C.C. of it are to be withdrawn and tested with the oxalic acid solution as before. The difference between the two results shows the number of milligrammes of lime which have been neutralized by the carbonic acid, and by multiplying this difference by 0.795, we obtain the number of C.C. of carbonic acid in the air examined. Deduct 60 C.C. from the total capacity of the jar (the space occupied by the lime-water put in), and state the remaining capacity in litres and decimals ; taking this as a divisor, and the number of C.C. of carbonic acid found as the dividend, the quotient is the C.C. of carbonic acid per 1,000 volumes of air.

when the baryta has become saturated by carbonic acid. In an alkaline solution, phenolphthalein is a brilliant crimson; when the solution containing it is exactly neutral it is colorless, and when it has become acid it is dull yellow; the doubt is as to whether this action is sufficiently prompt.

EXAMPLE.

The first alkalinity of lime-water was	39. for 30 C.C.
After exposure to the air in the jar it was	33. “
Difference, being milligrammes of lime	6. precipitated by CO_2 in jar.
Multiply by factor	0.795
	4.770 = total CO_2 in jar in C.C.
Capacity of jar	4385 C.C.
Deduct 60 C.C. for space taken up by lime-water	60
Net capacity	= 4325 C.C. = 4.325 litres.

Then $4.770 \div 4.325 = 1.103$ C.C. of CO_2 per litre, or volumes per 1,000. The factor 0.795 is obtained as follows: The difference between the two alkalinities expresses milligrammes of lime precipitated by CO_2; from this the milligrammes of CO_2 can be got by calculating from the ratios of the equivalents, thus:

$$\begin{array}{ccccccccc} \text{CaO.} & & CO_2. & & \text{Mgm. of CaO.} & & \text{Mgm. of } CO_2. & & \\ 56 & : & 44 & :: & a & : & 4 & : & \therefore\ x = a \times \frac{44}{56}. \end{array}$$

As one C.C. of CO_2 at 32° Fahr. (0° Cent.) weighs 1.9767 milligrammes, the ratio between weight and volume is $\frac{1}{1.9767} = 0.506$; $:: x \times 0.506 =$ C.C. of CO_2, corresponding to the milligrammes by weight. As 60 C.C. of lime-water were put into the jar, and only 30 C.C. taken, the result must be multiplied by 2. Therefore, the factors combined are: $\frac{44}{56} \times 0.506 \times 2 = 0.795$, and this multiplied by a, the difference between the two alkalinities, gives x the total C.C. of CO_2 in the jar.

If baryta be used instead of lime, it must be free from traces of potash and soda; a much smaller quantity of liquid may be employed, as it is so much more soluble than lime; the calculation is the same.

A correction for the temperature of the air examined must be made, the standard being 32° Fahr., or 0° C., the freezing point of water. If the temperature be above this (as it will generally be, at least in buildings), the air will be expanded, and a smaller quantity, by weight, consequently, will be operated on.

On the other hand, below 32° the air will be contracted, and a larger quantity, by weight, operated on than at the standard temperature. This can be corrected by adding 0.2 per cent. to the result for every degree above 32°, and subtracting it for every degree below; the reason being that air expands or contracts 0.2 per cent. for every degree (or 1 per cent. for every 5 degrees), it deviates from the standard. *Example:* In the preceding example the CO_2 was found to be 1.103 per 1,000. Suppose the temperature to have been 60° Fahr., then $60 - 32 = 28°$ to be corrected for; $28 \times 0.2 = 5.6$ per cent. to be added on to result, or the result must be multiplied by $1 + .056 = 1.056$, $\therefore 1.103 \times 1.056 = 1.154$ per 1,000, the corrected result. Suppose the temperature had been 25° Fahr., then $32 - 25 = 7°$ to be corrected for; $7 \times 0.2 = 1.4$ per cent. to be deducted, or the result must be multiplied by $1.00 - .014 = 0.986$ $\therefore$ $1.103 \times 0.986 = 1.087$, the corrected result.

A correction for pressure is not necessary, unless the place of observation be much removed from sea-level; in that case, the barometer must be observed, and a rule of three stated.

$$\left.\begin{array}{l}\text{As standard height of bar:}\\ (= 29.92 \text{ in.} = 760 \text{ mm.}):\end{array}\right\} \left\{\begin{array}{c}\text{Observed height}\\ \text{of bar}\end{array}\right\} :: a : x.$$

"The apparatus consists of two graduated glass flasks, Fig. 1, set in a revolving frame and connected by a glass tube furnished with a stop-cock. The tubes connect with the three-way cock, which allows air to enter one or the other of the flasks at pleasure. The U-shaped glass, Fig. 2, has eight bulbs blown on one of the legs, to insure the perfect absorption of the carbonic acid by the baryta-water.

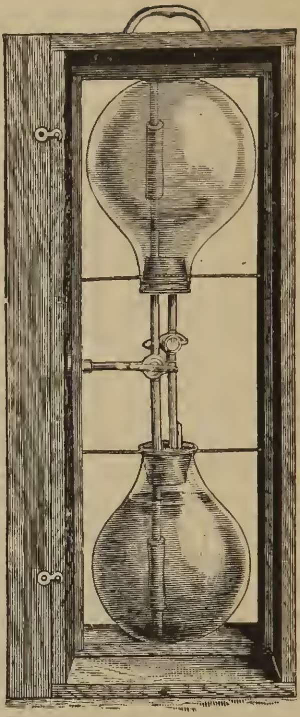

FIGURE 1.

"To use the apparatus, fill the upper flask to the zero mark with water (this may readily be done by attaching the end of the flexible tube to a faucet); pour into the absorption tube, through the funnel, from 12 to 15 centimetres of baryta-water containing 3.425 milligrammes of baryta (BaO), which will absorb one-half a cubic centimetre of carbonic acid gas; turn a three-way cock so as to connect the upper flask with the absorption tube; turn the stop-cock, so that the water will pass from the upper into the lower flask; aspirate slowly till the color disappears; shut the stop-cock and read on the graduated flask the number of cubic centimetres of water run out, and hence the amount of air passed through the baryta-water. If 1,000 C.C. of water have been used, the proportion of carbonic acid is 5 parts in 10,000. As air changes its volume under

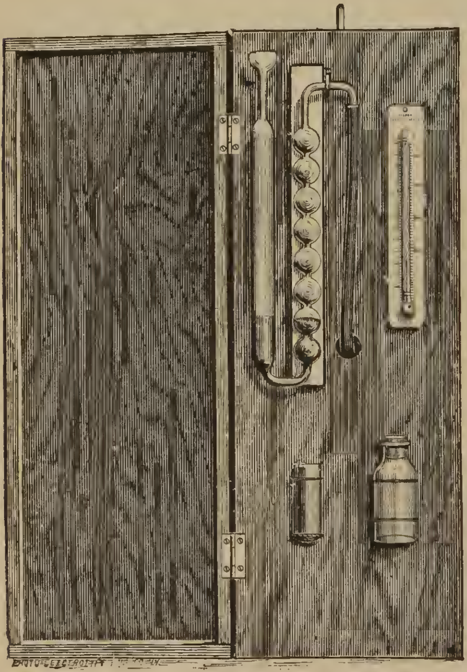

FIGURE 2.

hour, for each square foot of surface s, at which the air receives heat from the coil, and for each degree of difference between the temperature of the steam and the air of the room.

a co-efficient velocity, such that K $V=V'$.

=the unbalanced upward pressure of the base of the flue, due to the difference between D_a and D_c, or due to the difference in the weight between the two volumes of the height H within and outside the flue.

The following are some of the formulæ given by Prof. Trowbridge :

$$V=V\frac{2\,g\,H\,(T_c-T_a)}{T_a} \qquad (4)$$

$$Q=w\,c\,(T_c-T_a) \qquad (6)$$

$$S=\frac{K^2\ V^2\times W\,c\,T_a}{2\,g\,H\,(\frac{r(T_s-T_a)}{3{,}600}} \qquad (10)$$

$$W=D_c\ V\ A$$

$$S=\frac{K^2\,V^3\times D_c\,c\,T_a\,A}{2\,g\,H\,\frac{(r\,T_s-T_a)}{3{,}600}}$$

A being the area or cross-section of the flue.

Equations (10) and (11) represent the laws connecting the eating surface with the height of the chimney, the area the flue, and the temperature of the external air. They ow that the heating surface is directly proportional to the be of the velocity, to the area of the flue and to the temrature of the external air, and inversely proportional to e height of the chimney and the rate of transfer of the at r, or r (T_s-T_a).

It seems probable that a value of K between 3 and 4, and r between 2 and 2.5 will answer for ordinary cases. The aller values correspond to low velocities and large flues. l the larger values to high velocities and smaller flues. of. Trowbridge concludes that steam coils are more nomical than blowers as a means of producing movet of air in a ventilating flue.

o obtain a large amount of heating surface with a minm quantity of steam pipe, he suggests the separation e pipes by sheet iron diaphragms which are heated by ation from the pipes. This device will, however, have ffect on the amount of heat which must be furnished e coil to produce the desired effect.

VENTILATION FORMULÆ.

The School of Mines Quarterly, for March, contains a per by Prof. W. P. Trowbridge, on the determination of ating surface required in ventilating flues, in which an empt is made to show how this may be calculated by thematical formulæ :

et it be supposed that the air in the room is to be ewed at the rate of W pounds per second. The vole of this quantity of air can easily be determined when temperature is given. Suppose also that it is to be cted through a vertical flue whose cross-section is A, whose height is H, and that it is to be heated by m coils at the base of the flue, having a total exterior face equal to S.

The following notation is used :

V=weight of air discharged per second.
I=height of flue.
=the exterior surface of steam coil.
=area of cross-section of flue.
$_a$ =the absolute temperature of the external air, *i. e.*, the common temperature Fahrenheit + 459, 4°.
$_c$ = the absolute temperature of the air in the flue.
$_s$ = the temperature of the steam in the coils.
$_a$ = the weight of a cubic foot of the external air.
$_c$ = the weight of a cubic foot of the air in the flue.
V′=the theoretical velocity of the air in the flue.
V=its actual velocity when frictional resistances are taken into account, r=the rate in units of heat per

varying pressures and temperatures, corrections must be made for these in order to obtain absolutely correct results. To save calculation, a table has been prepared, giving the volume of 1,000 cubic centimetres of air at 32° Fahr., and 30 inches barometric pressure, when under pressure varying from 29 to 31 inches, and temperatures from 40° to 90°. By a reference to a diagram, which has also been prepared, the proportion of carbonic acid in the corrected amount of air, as taken from the table, may be seen at a glance.

"Should it be necessary to pass more air through the baryta solution than is contained in one flask, close the stop-cock ; close the air hole in the flask containing the water ; revolve the aspirator ; open the air hole in the empty flask ; reverse the three-way cock, and proceed as before."

I strongly advise all architects to learn how to make this test, for it is only in this manner that they can prove that their buildings are properly ventilated, or can decide positively on the merits of the dozens of patent ventilating appliances, which are fast becoming as much of a nuisance as patent lightning rods.

It is true that other tests should be applied in connection with this, and it is also true that by measuring carefully the quantity of air entering a room in a given time, and taking this result in connection with the position of registers, etc., a person of experience can form a very accurate and reliable opinion as to the character of the ventilation of the room ; but as explained above, the phrase, "good ventilation," implies a thorough mixing of the foul air with that which is pure, and the chemical test is the only one which will show whether this mixing has been effected or not.

In this connection let me offer a bit of advice which may save some time and annoyance. When the gentleman with the "Automatic Zephyr Ventilator," or the "Breath of Spring Pulsifier," or the "Sanitary Grate," or the "Foul-air Exterminating Stove," calls on you and begins to unroll his tin models, or to ask you to read the certificates of Prof. Tuthick and others, ask him where the air analyses are for his invention, and when he says he has none, tell him that until he gets them from some reputable chemist you really cannot spare time to look into the matter. It is not your business to investigate the value of his patent ; it is his business to prove it to you, and this proof must be the detailed analysis.

If any patentee ever took the trouble to obtain such proof I am not aware of it.

In this connection attention should be called to a property of air which is important in ventilation problems, although it is hardly alluded to in books, and that is its adhesion to surfaces, even when in motion.

The best mode of illustrating it is, perhaps, an experiment devised by the late Professor Joseph Henry. Upon a large, smooth table, sprinkle uniformly some light powder, such as powdered lycopodium. In the middle of the table place a bell glass, mouth downward. Then with a pair of bellows direct a current of air from the edge of the table toward the centre of the bell glass. The track of this current will be distinctly marked in the powder, and when it reaches the bell glass you will see it divide in two parts, one passing on one side, the other on the other, but both adhering to the glass until they meet on the opposite side, when they will join and continue in their original direction.

When a current of air is started along a wall or floor, it may adhere to it for several feet, or even yards, and in this way we may have annoying draughts at points where we had least expected them.

In the hall of the House of Representatives, at Washington, a few years ago, a large part of the fresh air was brought in through the risers of the platforms upon which the chairs of the members are placed. This sheet of air, introduced under pressure, and in a horizontal direction, did not diffuse directly upward, as it was intended to do, but adhered to the floor, and swept across the ankles of the member just in front. When it had passed his desk and reached the next riser, it was reinforced by a fresh stratum, and the honorable member next in front received the upper current on the calves of his honorable legs, while the floor current swept his ankles, to his great discomfort and dissatisfaction.

In like manner I have seen a warm air register so placed in the floor in the corner of a room, that the entering air adhered to the sides of the room and passed directly upward, almost as if it were in a tube. It then streamed along the ceiling to an opening into a foul air flue in the opposite corner, and passed out without disturbing the air in the lower part of the room.

In this way it may happen that a sufficient quantity of air may be passing into and out of a room and yet that the ventilation may be extremely unsatisfactory. It is necessary to secure distribution as well as entrance and exit.

CHAPTER II.

HEAT, AND SOME OF THE LAWS WHICH GOVERN ITS PRODUCTION AND COMMUNICATION—MOVEMENTS OF HEATED AIR—MOVEMENTS OF AIR IN FLUES—SHAPES AND SIZES OF FLUES AND CHIMNEYS.

My architectural friend, in the letter to which allusion was made at the commencement of the last chapter, said: "I do not care for scientific theorizing and speculations in this matter; what I want are practical rules." Probably he would class as "scientific theorizing" the following statements with regard to some of the laws in accordance with which heat is produced and transmitted, and the movements of air and gases take place, yet it is necessary to understand them in order that the "rules" which depend upon them may be applied in each particular case, so as to be really "practical" and useful.

This "science," in regard to which distrust, and often more or less contempt, is so frequently expressed is, after all, only another name for the results obtained by trained common sense from comparisons of facts carefully observed and accurately recorded.

As to theorizing, we must do that at nearly every step, for there are few of our plans in which we are not compelled to rely on probabilities instead of certainties. That the amount of daylight next year will be about the same as in preceding years; that we shall have life and health to finish the plans which we promise to prepare; that the coldest day during the next twenty years will not be colder than the coldest day during the past twenty years; and that the price of labor and materials will not vary beyond a certain amount within the next two or three years—all these are theories which we accept and act on when we proceed to make plans and estimates for a building, and, moreover, they are scientific theories. What we should really wish to avoid is unscientific theorizing, and the best way to do this is to learn to recognize it when we meet with it—which will be daily.

In these remarks I do not by any means wish to be understood as undervaluing the importance of that knowledge which comes from practical experience. Every intelligent workman who has been engaged in making and setting heating apparatus, and has had any opportunity of observing the results, possesses valuable information which might be very useful to a scientific engineer.

These detached observations, however, are of small value until they are seen in their true relations with the general principles or laws which govern the operation of such apparatus, and a mere rule-of-thumb knowledge sometimes leads to very awkward mistakes when an attempt is made to apply it where the circumstances vary from those under which it was originally acquired. The laws of heat and of pneumatics are uniform and apply to all cases. We do not, by any means, know all these laws, but we have discovered some of them, and whenever we find any apparent contradiction to these—when the flue draws the wrong way, or the room gets cold when it ought to be hot—we may be sure that the error is with us and not with science. The distinction drawn by Herschel is an important one: "Art is the application of knowledge to a practical end. If the knowledge be merely accumulated experience, the art is empirical; but if it be experience reasoned upon and brought under general principles, it assumes a higher character and becomes a scientific art."

Heat and cold are often spoken of as if they were material substances. We hear of driving out or shutting out the cold, of heat flowing from one body into another, etc. Heat is a force—cold is the absence or diminution of this force. Substituting a definition of force, we say that heat is a mode of motion—of motion of particles of matter—and this matter may be gaseous, liquid or solid. Heat is usually said to be communicated from one body to another by three processes, known as radiation, conduction and convection. Radiant heat passes from one body, through gases, or through what is usually called a vacuum, to another body at a distance, going in straight lines and with great velocity. It does not heat to an appreciable degree the gas through which it passes. Conducted heat passes from one particle of matter to another at insensible distances. If the particle of matter is free to move among other particles, as in liquids and gases, it may carry heat from one point to another; and this is what is called convection, which is really a mixture of conduction and radiation. Heat can only pass with great difficulty, if at all, from one particle of liquid or gas to another particle of liquid or gas—but it passes readily between these and solids. In attempting to heat by means of warm water, steam or hot air, it is necessary to remember this, and that the securing a thorough circulation, so that every particle of the water or air comes successively in contact with the heated solid walls of the furnace or radiators, is essential to success.

We measure heat in two ways. The first is by the thermometer, which shows how much warmer or colder than melting ice its immediate vicinity is. The second is by what is called the thermal unit, which in Great Britain and in this country is the amount of heat which is required to raise the temperature of one pound of water one degree Fahrenheit. One pound of coal completely burned will give from 13,000 to 14,000 such thermal units, but in no form of grate, furnace or heating apparatus is this complete combustion effected, nor can all the heat derived from that which is burned be made available for heating purposes. In an ordinary steam boiler from 6,000 to 8,000 heat units are utilized in the production of steam, the rest being lost from imperfect combustion, in the air which passes up the chimney, by radiation in the boiler house, etc.

The amount of force in one thermal unit will raise 772 lbs. one foot high, or is equal to 772 foot pounds. At the average temperature and pressure, a little over 13 cubic feet of air make one pound. One thermal unit will raise the temperature of one pound of air 42° F. Therefore, one pound of coal will heat 8,000 cubic feet of air about 50° F., or it will lift 104,000 cubic feet of air about 385 feet, but it will not do both. You may do much to secure complete combustion of coal and to prevent waste of heat ; you may obtain the power to move the air from the coal, either directly by heating and expanding the air, or indirectly by producing steam power with which a fan or pump may be worked, but it is desirable to understand clearly that but a certain number of heat units can be obtained at best from a given quantity of fuel, and that while these heat units may be used either to heat or to ventilate a room, you cannot use the same units for both purposes. After all, you can only get 100 per cent. of effect. You will, however, find inventors claiming much more than this for their special appliances, and a remembrance of this percentage rule will sometimes save much useless trouble in examining plans or proposals.

To completely burn one pound of coal requires about 295 cubic feet of air, and all the nitrogen, oxygen, carbonic acid, and vapor of water in this air must be heated, and will therefore absorb and carry off some of the thermal units. Whatever may be the methods of ventilation employed, there is but one mode of getting rid of the products of combustion of fuel that need be mentioned here, and that is by using the force due to the expansion of gases by heat.

The air has weight. A column of it one inch square extending from the ground to the top of the aerial ocean weighs about fourteen and a half pounds ; in other words, the air presses on the earth, and on all things on the surface of the earth, with a force of 14.6 lbs. to the square inch. This pressure is not merely directly downward, but in all directions ; it presses outward from our lungs with a force of 14.6 lbs. per square inch, and if it did not, our chests would be crushed with the external pressure on them, which amounts to over four tons. If at any point the pressure be diminished the surrounding air tends to rush in and equalize it. If, then, we can diminish the pressure at any point, we shall have a force which will be available for moving air toward that point, and if we increase the pressure the force will be available for moving air away from that point. One of the readiest means of diminishing or increasing the pressure of the air is by the addition or subtraction of heat. When we heat air, which is not confined in an air-tight space, it expands—its particles or molecules go further apart, so that the same number which occupied a cubic foot may, when heated, occupy two cubic feet, and hence one cubic foot of air thus heated weighs only half as much as it did before.

The result is that, if it be free to move, the heavy surrounding air flows in from all sides and pushes the lighter heated air upward, just as water forces wood which is lighter than itself to its surface. If we confine the heated air in a chimney, the difference between the weight of the column in the chimney and that of a precisely similar column of the air outside the chimney is the measure of the force with which the heated air tends to rise in the flue. On the other hand, when we cool air it contracts in bulk, and a cubic foot of air thus chilled and contracted weighs more than the same volume of air not cooled.

If the air in a flue is cooler than the surrounding air in connection with it, it will flow downward, and the measure of the force is the same as in the case of the heated flue. Air expands $\frac{1}{491}$ of its bulk at 32° F. for every degree Fahrenheit it is heated. For example, if the air in a chimney be heated 50° F. above the surrounding air it will be increased in bulk as 1 is to $1 + \frac{50}{491}$, or $\frac{1}{10}$ nearly. The force with which the gases from the burning fuel tend to rise in a chimney may be, under ordinary circumstances, measured by the temperature at which these gases enter the flue. The lower this temperature, the more economical the apparatus, so far as heating is concerned. From an ordinary steam boiler the products of combustion enter the chimney at a temperature of 550° F.

From a good hot water boiler, properly fired, these products of combustion enter the chimney at about 300° F., the temperature of the water in the boiler being 160° F., while from a so-called air-tight stove, with a large amount of pipe, they may pass into the chimney at 150°, or even so low as 100° F.

These are merely average figures. By special arrangements it is possible to cause the gases from the furnace of a steam boiler to enter the chimney at a much lower temperature, even as low as from a stove, but such apparatus is seldom used, since with coal at present prices it seems cheaper, on the whole, to use the usual forms of apparatus.

Heated air in a bottle having a narrow, open mouth will not rise, because the colder air around cannot enter to force it out; but if the mouth be divided by a partition, a current will soon be established, the cold air flowing down on one side and the warm air streaming up the other. This is commonly illustrated by those advocating the use of a patent ventilator which depends on this principle, by an experiment which always deeply impresses those who see it for the first time, and the exhibition of which has sold many ventilators—and purchasers. This experiment consists in placing a short piece of lighted candle in the bottom of the bottle. The heat of the flame promptly sets up a circulation within the bottle, which continues until enough carbonic acid has been produced to extinguish the light. If just before the light goes out a partition be inserted in the neck of the bottle the effect above mentioned will be produced; the smoke will be seen streaming out on one side, and the light will soon burn again as brightly as ever. For ventilating a bottle, or a place which is under the same conditions as a bottle, this is a very good method; but if you ever put such an arrangement into a house you will find that when cold weather comes it will be carefully closed. On the other hand, warm air will not rise in a room filled with cold air unless this room has some opening by which some of its contained air will escape. Forgetfulness or ignorance of this fact sometimes causes great disappointment to the amateur furnance-setter, who cannot imagine why his apparatus will not heat a room above it in which every aperture has been closed "to keep in the heat." The quickest way to heat a room under such circumstances is to open the window. It will be found useful to remember the bottle and the demoralized furnace-setter when a client complains of a smoky chimney.

I have now to call attention to some facts connected with the movement of air in tubes or flues, and through outlets of various kinds. Such movement is in many respects in accordance with the laws that govern the movement of liquids under like circumstances. The first thing to be done in determining the amount of discharge through any opening is to find the velocity, and for openings, flues and chimneys, as yet unconstructed, this velocity must be calculated. The calculation cannot be made accurate, as we shall see, but very useful results may be obtained from it. The theoretical velocity, when friction is not taken into account, is calculated in several ways, but that which is now most commonly used depends upon what is known as the law of Montgolfier, or the law of spouting fluids. This law is that fluids pass through an opening in a partition with that velocity which a body would attain in falling through a height equal to the difference in depth of the fluid on the two sides of the partition, or, what is the same thing, the difference in pressure on two sides. The velocity in feet per second of falling bodies is about eight times the square root of the height from which they have fallen expressed in feet, and the formula for determining this is $v = c\sqrt{2\ g\ h}$.

In this equation v is the velocity to be found, stated in feet per second; g is the velocity which a body falling freely from a state of rest has at the end of one second—which is 32.2 feet per second; h is the distance fallen through by the body; and c is a constant determined by experiment, which expresses the proportion of the actual to the theoretical velocity.

The height h fallen through by the cold air is to be determined by the law of the expansion of gases, which for our purpose may with sufficient accuracy be taken to be $\frac{1}{491}$ of its volume for each degree F. of increase of temperature. In the case of a chimney flue, as explained above, the force which drives the warm air up the flue is the force of gravity—of the excess of gravity or weight of a column of cold air over a precisely similar column of warm or expanded air, which is the difference in pressure above referred to.

This difference in pressure is found by multiplying the height from the opening at which the air enters the flue to that from which it escapes by the difference in temperature outside and inside, and again multiplying this product by $\frac{1}{491}$. The formula for the theoretical velocity then becomes

$$v = 8\sqrt{\frac{(t-t) \times h}{491}}$$

in which t is the temperature in the chimney, t' the temperature of the external air, and h the height of the chimney.

Suppose, for example, that the temperature in the chimney is 100°, that of the external air 40°, and that the chimney is 50 feet high, we shall have

$$v = 8\sqrt{\frac{60 \times 50}{491}} = 8\sqrt{16.11} = 20$$

nearly, or the theoretical velocity would be twenty feet per second.

This theoretical velocity will be diminished by friction, by angles in pipes and flues, and by eddies or counter-currents, and on the other hand it may be increased by the aspirating force of wind passing across the top of the flue.

The general rule is that the real velocity in a chimney flue will be less than the theoretical velocity by from 20 to 50 per cent. It is because of this difference that minute calculations are useless, and that I have preferred to give a slightly inaccurate formula because of its simplicity and the ease with which it can be remembered. From what has been said it will be seen that the velocity of the ascending column of air in a heated chimney depends upon the difference in temperature between the [illegible] the chimney and that outside. The greater this difference up to temperatures of 800° F., the greater the velocity, other things being equal. The velocity also depends on the height of the chimney, the general rule being that the velocity increases with the height. This, however, is neither theoretically nor practically correct, except within certain limits. The formula assumes that we use in our calculations the mean temperature of the shaft. It must be remembered that there is a very considerable loss of heat from the external surface of the chimney itself, and the higher the shaft the greater the amount of this surface and the greater the loss, thus neutralizing to a certain extent the effect of the increase in height. The amount of air which passes up the chimney depends on the area of the flue and the velocity, the formula being $q = a \times v$.

In ventilation problems, we usually determine first the quantity of air which the flue is to transmit in a given time, and then, assuming such figure for the velocity as may seem best under the circumstances, calculate the area of the flue by the formula

$$a = \frac{q}{v}.$$

The problems relating to velocities of currents and areas of flues, more especially in chimneys, are comparatively simple, if the nature of the force which produces draught in a chimney be clearly understood —but the popular mind is by no means clear on this point. Many persons seem to suppose that a chimney has some independent power of its own, and in this sense say that it draws well or draws badly. I have heard a mason contend that the chimney itself must do some of the work, independent of heat, because in a house which he was then at work on, he found an upward current in the chimney, although the roof had not yet been placed on the building, and it required several trials under different circumstances to convince him that this current was due to the heating by the sun of the south wall in which the chimney was placed.

Of course, if a chimney had any such power as he supposed, we should have a sort of perpetual motion, and, as Mr. Edwards remarks, upon this theory it would only be necessary to build a few gigantic chimneys to work all the mills in a place without the use of coal.

In deciding upon the velocity to be maintained in a chimney shaft, which velocity is to be used as the basis of calculation for sizes of flues, the following considerations must be kept in mind :

The velocity should be sufficient to maintain a steady, uniform flow, without eddies or currents; and, at the mouth of the chimney, it should be so great that the usual winds will not interfere with it, which will necessitate a rate of about 10 feet per second. If it be greater than this there will be a waste of fuel, for we have seen that this velocity depends upon the temperature to which the air is heated, and every unit of heat contained in the air escaping at the mouth of the chimney which is in excess of the number of units required to prevent eddies and counter-currents, is so much useless expenditure. It is, moreover, quite unnecessary to keep the velocity in the shaft as great as that at the outlet; and it is very poor economy to do it, because the friction increases rapidly with increase of velocity, and requires more force, or, what is the same thing, more fuel, to overcome it. The velocity in the main flue of the chimney of an ordinary dwelling-house should be about five feet per second, whence it follows that the area of opening at the mouth of the chimney should be about one-half that of the main flue.

The increase of temperature in the chimney which will be required to produce this velocity depends, of course, upon its height, but for a shaft about 40 feet high the increase over that of the external air should be about 40° F.

Of late years the tendency of architects and builders in this country has been to make their flues too small, which is probably due to the very general use of stoves. In shunning this error care must be taken not to fall into the opposite extreme, for "the expedient of constructing everything a little larger than is necessary in order to have a reserve for contingencies is not always a safe one," at least if due regard be given to economy. If a chimney shaft has a larger area than is necessary, down draughts will be formed in it when a sufficient supply of heated air is not provided for it, while if this supply be given, more air, and therefore more heat, than is requisite must be furnished. The use of movable valves or dampers at the base of the shaft will prevent the last evil, but will aggravate the first; and the same is true as regards the very common expedient of a valved opening at the base of the shaft to allow air from the boiler room to enter the chimney direct, and therefore diminish the draught. If the valve be placed at the top of the shaft both evils may be corrected within certain limits, and such valves will sometimes be found of great use.

The shape of the flue should be as nearly round or square as the size of the walls and jamb will permit. The circle is the best form, because it gives the greatest area in proportion to the perimeter, or surface producing friction, and the square is next. If the flue be rectangular in shape, with one diameter of not more than 4 inches, the friction will be great, and if such a flue be so placed in a wall that one of its long sides is parallel to a surface of the wall which is exposed to cold air, there will be great loss of heat.

If we consider chimney flues as intended only to carry off the products of combustion, without reference to questions of ventilation, the following are the sizes which give the best results: For ordinary dwelling-houses the flue for each room, if built of brick in the usual way, should be about one foot square, or for common bed-rooms 9″x 12″. If the flues be lined with smooth pipes of pottery or cement they may be 9″ in diameter.

The sizes of chimney flues used in ordinary dwellings vary in different parts of the country. In Boston, New York and Chicago such flues are usually 8″x 8″ or 8″x 12″. In Baltimore the flues are usually 13″x 13″. In New Orleans the common size is 9″x 9″.

This difference depends in part on the variation in size of brick in common use, in part upon the more general use of closed iron stoves in the North, and in part to traditions of masons and builders, of which it would be very difficult to trace the origin. Tredgold's rule for chimneys for steam boilers is as follows: "The area of a chimney in inches for a low pressure steam engine, when above 10 horse power, should be 112 times the horse power of the engine, divided by the square root of the height of the chimney in feet. *Example:* Required the area of a chimney for an engine of 40 horse power, the height of it being 70 feet.

"In this case

$$\frac{40 \times 112}{\sqrt{70}} = 533.2$$

square inches. The square root of this is 23 inches, which will be the side of a square chimney. Or, multiply 533 by 1.27 and extract the square root for the diameter of a circular one."

In another place, however, Mr. Tredgold advises that chimneys be built double the size called for by this rule. Mr. Milne substitutes 280 for 112 in the above formula, and thus obtains results between two and three times as great. Milne's rule is as follows: The square root of the height of the chimney in feet multiplied by the square of its internal diameter at the top or narrowest part in feet is equal to twice the nominal horse power for the chimney.

By horse power in this connection is meant the evaporation of a certain amount of water—the usual estimate being that a cubic foot of water at 60° evaporated to steam is equal to one nominal horse power, which, in round numbers, would require 70,000 thermal units.

The judges at the Centennial defined a horse power to be equal to the evaporation of 30 lbs. of water from a temperature of 212°. As a cubic foot of water weighs a little over 62 lbs., this standard requires less than half the fuel which would be needed for the former—being only about 29,000 thermal units. Taking the older and more usual estimates used by Tredgold, allowing 8 lbs. of coal per hour per horse power and 300 cubic feet of air for the combustion of each pound of coal, we find that we shall have for a 40 horse power boiler about 30 cubic feet of gases per second to dispose of. If we allow a velocity of five feet per second in the flue we shall want a flue having an area of six square feet, which result is intermediate between those of Tredgold and Milne, and is probably more nearly correct than either.

Another rule is that of Murray—18 square inches for 12 lbs. of coal per hour.

Another rough-and-ready rule for chimneys for the ordinary horizontal flue boilers is, that the chimney should be from 60 to 80 feet high, and have an area equal to half the square of the diameter of one of the tubes multiplied by the number of tubes. In such a boiler, 15 feet of boiler surface is taken as equal to one horse power. Still another rule-of-thumb is, that the size of the flue should be equal to the area of the tubes.

In this connection it may perhaps be well to say a word about smoky chimneys, although in this country we are not troubled with them to anything like the extent that they are in England, judging from the amount of English literature on that subject. This is due to the fact that we do not use open fire-places nearly so much as they do in England, and that we have a much drier climate. In some of our public buildings where open grates are used there has been trouble from smoke, and Mr. Briggs once gave me a very amusing account of the efforts made to cure it in one of the large public buildings in Washington, in which there was a series of rooms freely communicating with each other, and each having an open grate. When the watchman began to build the fires in the morning he found the first one had a magnificent draught, the second one not so good, the third very dubious indeed, and the fourth smoked furiously. Then came the chimney doctor with a patent chimney top, which was placed on flue No. 4, lengthening it about three feet. No. 4 now drew well, but No. 3 was no longer dubious, for it smoked like a tar kiln. Of course, the same remedy was applied to No. 3, but then Nos. 1 and 2 became a nuisance. When these also had been duly furnished with the patent chimney tops, all the flues were again of the same height, and the process had to be begun *de novo*. The true remedy in such a case is to see that each chimney has its own sufficient supply of air from without, and does not draw against another flue.

A damp flue is another cause of smoky chimneys, since the current of ascending air is rapidly cooled by evaporation. This often adds greatly to the difficulty of keeping a smoke flue situated in an outer wall in good working condition.

The effects of wind on the action of chimneys will be considered hereafter.

CHAPTER III.

AMOUNT OF AIR SUPPLY REQUIRED—CUBIC SPACE.

In preparing plans and specifications for heating and ventilating a building, one of the first things to be done is to decide as to the amount of fresh air that is to be supplied, and it is just at this point in his studies that the young architect or engineer is most likely to become demoralized and discouraged. On consulting his text-books and manuals he finds the greatest diversity of opinion as to the proper methods of calculating this amount, and that the several methods proposed lead to the most discordant results; the effect of which is often that he concludes that none of these opinions have any scientific basis, and that really it don't make much difference whether any special attention is given to the matter or not.

Engineers usually base their estimates as to quantity of air upon data given by chemists and physicists with regard to the various offices which this air has to fulfill.

For instance, Box, in his "Practical Treatise on Heat"—one of the most convenient manuals on this subject—divides these offices into five, viz., to support respiration, to carry off vapor, to carry off the exhalations, to carry off the animal heat, and for the lighting apparatus, and tabulates these as follows:

Cubic Feet of Air required for the different purposes of Ventilation.

Character of Occupants.	For Respiration.	For Vapor.	For Exhalation.	For Heat.	For Lights.
Room with single occupant, cleanly and healthy	22	237	250	220	60
Room with single occupant, healthy, but not cleanly	22	237	350	220	60
Room with single occupant, cleanly, but sick	22	237	1,000	220	60
Crowded room, healthy and cleanly persons	22	237	250	500	60
Hospitals (ordinary cases)	22	237	2,000	220	60
Hospitals for fevers, etc.	22	237	4,000	220	60

He observes that the same air may serve simultaneously or consecutively for all these five purposes, and concludes that for a clean and healthy person 250 cubic feet per hour is sufficient, basing his subsequent calculations on 220 feet per hour as a minimum, in which he follows Péclet.

The fallacy in this lies in the assumption that the used and contaminated air does not mix with and defile the air in the room, but passes off at once—an assumption which is entirely incorrect in the great majority of cases, and would only hold good if each person inspired air from one reservoir and expired it into a totally different one.

General Morin's estimates, which are those most frequently quoted, but which Box erroneously criticises as being in many cases excessive, are shown by the following table:

Places Ventilated.	Cubic feet of air per head per hour.			Authority.
	Max.	Min.	Mean.	
Hospitals	......	......	2,120	Péclet.
Theatres, Assembly Rooms, etc	......	......	530	"
Prisons	......	......	350	"
Ordinary Rooms	390	212	300	"
Schools	......	......	212	"
Hospitals, ordinary maladies	......	......	2,470	Morin.
" wounded, etc	......	......	3,530	"
" in times of epidemic	......	......	5,300	"
Theatres	1,760	1,410	1,585	"
Assembly Rooms, prolonged sittings	......	......	2,120	"
Prisons	......	......	1,760	"
Workshops, ordinary	......	......	2,120	"
" insalubrious	......	......	3,530	"
Barracks, during the day	......	......	1,060	"
" " " night	......	......	1,760	"
Schools, infant	706	530	618	"
" adult	1,410	1,060	1,235	"
Stables	7,060	6,350	6,700	"

The estimates of sanitarians as to the amount of air required are now based upon the observations of De Chaumont, Parkes, and others, as to the amount needed to keep an occupied room free from perceptible odor to a person entering it from the outer air, and on the percentage of carbonic acid which is found in the air of rooms in which this animal odor is barely perceptible.

As I have stated above, when, as a product of respiration, the proportion of carbonic acid in a room is increased from the normal ratio of between 3 and 4 parts in 10,000 to between 6 and 7 parts in 10,000, a faint, musty odor is usually perceptible. Assuming that the air of an inhabited room should not be so impure as to possess this odor, the following table by Parkes shows the amount of air necessary to dilute to this standard:

Amount of cubic space (breathing space) for one man, in cubic feet.	Ratio per 1,000 of carbonic acid from respiration at the end of one hour if there has been no change of air.	Amount of air necessary to dilute to standard of .2, or including the initial carbonic acid, of .6 per 1,000 volumes during the first hour.	Amount necessary to dilute to the given standard every hour after the first.
100	6.00	2,900	3,000
200	3.00	2,800	3,000
300	2.00	2,700	3,000
400	1.50	2,600	3,000
500	1.20	2,500	3,000
600	1.00	2,400	3,000
700	0.85	2,300	3,000
800	0.75	2,200	3,000
900	0.66	2,100	3,000
1,000	0.60	2,000	3,000

The above table refers to rooms occupied for a number of hours consecutively.

In any given case the amount of air required for each room will depend on the dimensions of the room, the difference between the external and internal temperatures, the number of persons occupying it, their character or occupation, and the length of time they are to remain in it. With regard to the first and second points, it may be observed that for an ordinary room in a dwelling-house which is to be heated by any method of indirect radiation—that is, by warm air—it will be necessary, in order to secure satisfactory warming when the temperature of the external air is below the freezing point, and the room has the usual proportion of external wall and window surface, that the amount of air supply per hour shall be about one and a half times the cubic contents of the room. Unless this amount of change be secured, either the room will not be kept comfortably warm, or the fresh air must be introduced at a much higher temperature than is desirable for health or comfort.

This rule will not apply to very lofty rooms, and, so far as heating and ventilation only are concerned, it is not desirable that rooms should be more than 14 feet high, even if very large, while for ordinary living rooms from 10 to 12 feet are the most satisfactory heights.

The higher the external temperature the more air is required to secure comfort up to the point where the air becomes so warm and moist that it no longer serves to remove the animal heat. There are days in summer when sufficient ventilation to secure comfort cannot be secured even out of doors, and in a crowd this is not at all uncommon.

As will be seen from the table given above, the allowance of 3,000 cubic feet of air per hour per head is that given by Parkes, and this has been accepted by most modern sanitarians. As a matter of fact, this amount of supply is very rarely obtained in cold weather through the flues and registers provided for fresh air supply. The entrance of fresh air is, however, by no means limited to such registers, and the health of the residents of many houses depends on the crevices around the windows and doors and at the base of the shrunken wash-boards, and on the fact that air goes through a brick wall covered with ordinary plaster with great facility. Bad construction thus sometimes prevents the evil effects of bad plans. Assuming that all the fresh air is to enter through the ducts provided for that purpose, and that we are to deal with substantial buildings having thick walls, rendered more or less impermeable by paint, paper, etc., I would advise that heating surface, foul and fresh air flues and registers be provided for an air supply of one cubic foot per second per head for rooms which are to be occupied constantly.

If this be done, it will be comparatively easy to adjust these appliances to a supply of but half the above amount, if this be all that the occupant is willing to pay for; whereas, if they be planned for the smaller supply, it will be impossible for them to meet the larger demands which the educated and thinking portion of the community are already beginning to make, and which will steadily increase. When the room is to be occupied but three or four hours at a time, and is thoroughly aired in the interval, the amount may be reduced to 2,500 cubic feet per hour, or three-quarters of a foot per second. This, for instance, is a proper allowance for school-rooms, halls of assembly, theatres, etc. I do not think it worth while to make any distinction between children and adults as to the amount of fresh air required. For rooms constantly occupied Roth and Lex fix the amount at 100 cubic metres, or about 3,500 cubic feet per hour.

These quantities are given as being the least which the architect or engineer should strive to secure, but every one agrees that it is desirable to obtain larger amounts where this can be done without materially increasing the cost. Other things being equal, the more air the better.

In the open air, with the temperature at 60° F., and when there is no perceptible wind, about 32,400 cubic feet of air per hour will flow over or come in contact with the person of a man, supposing his body to present an area of about nine square feet, and the displacement of air to be at the rate of one foot per second. In comparison with this, the allowance of 3,600 feet per hour certainly seems insignificant. It should be remembered, however, that this is the cold weather allowance, when the incoming air must be warmed, and that in summer the amount should be increased as much as possible, since to do so does not produce increased cost.

For about six months in the year the air may be allowed to sweep freely through inhabited rooms, and the architect may do much to secure facilities for its doing so more commonly than is usually the case. I shall allude to this again in speaking of methods of distribution, and the subject of amount of air supply will also receive further consideration when we come to speak of assembly halls.

In intimate connection with the subject of amount of air supply is that of cubic and floor space to be allowed each individual. Discussions on this point usually relate to soldiers' barracks or to hospital wards, but it also comes up in legislation relative to the accommodations to be furnished in common lodging or tenement houses. This question of cubic space is now looked on in a very different light from that in which it was considered twenty-five years ago. English writers of that date often made their calculations as to ventilation entirely or mainly with reference to the cubic space concerned—that is to say, they would prescribe that all the air in a room should be changed so many times per hour, and the estimates for amount of heating surface were based almost entirely on the cubic contents of the room or building to be heated.

So far as heating is concerned, this mode of calculation is still extensively used, but it will often give very unsatisfactory results, and it should be distinctly understood that, so far as ventilation is concerned, the number of persons, lights and fires to be supplied with air, and the quantity of air to be allowed for each, are much more important factors in the problem than the cubic space. A certain amount of space is necessary to secure the required change of air without perceptible, or at least uncomfortable, currents or draughts, and under ordinary circumstances the larger the space per person the easier it is to secure ventilation without discomfort. The ventilation referred to in this remark is what may be called "good" as distinguished from "perfect," as was explained in the first chapter, in which "good" ventilation was defined to be that which would keep the vitiated air in a room constantly diluted to a certain standard.

In calculations with regard to this standard it has been assumed that all the impurities derived from respiration, exhalation from the skin, etc., are constantly, quickly and thoroughly mixed with the total air of the room. This assumption is usually incorrect, for the diffusion of gases does not go on so rapidly as to overcome the effects of currents of air of different temperatures, which cause sometimes marked differences in the composition of the upper and lower strata of air in a room.

In such cases, however, it will usually be found that the upper strata are the most impure, as well as of a higher temperature. If uniform diffusion of the incoming air be supposed, the same supply of air is required to ventilate a large space as a small one, if the same amount of foul air be produced in each.

The formula for the amount of fresh air necessary to reduce a vitiated atmosphere to a required standard of purity is given by Dr. De Chaumont as follows:

Let R be the ratio of carbonic acid in incoming air.
“ r' “ “ “ “ vitiated air.
“ c be the capacity of original air space in cubic feet.
“ r be the desired ratio of purity to which r' is to be reduced.
“ d be the delivery of fresh air in cubic feet.
“ v be the total volume of air, $= c + d$.

Then: $\frac{r' - R}{r - R} \times c = v$, and $v - c = d$.

It will be at once seen by the above formula that when $r = R$, that is, when it is wished to restore c to the purity of the external air, v and d become *infinity*, so that complete purification of c is, under those circumstances, theoretically impossible.

To determine the number of men, n, a cubic space, c, will accommodate, we have the following, r and R being the ratio per cubic foot, e the CO_2 expired by one man in an hour ($=.6$ cubic feet), and h the number of hours:

$$\frac{(r - R)\,v}{e\ \ h} = n.$$

To determine the delivery of air required to retain an occupied space at a given ratio of purity, r, we have:

$$\frac{n\ e\ h}{R - r} = v, \text{ and } v - c = d.$$

In computing cubic space for purposes of ventilation, heights of rooms above 12 feet should be disregarded. With this limitation the minimum amount of cubic space per head which should be given may be stated as follows:

In a common lodging or tenement house, - - - -	300
In a school-room, - - . - - - - -	250
In a barrack dormitory for soldiers or police, - - - -	600
In an ordinary hospital ward, - - - - - -	1,000
In a fever or surgical ward, - - - - - -	1,400

CHAPTER IV.

METHODS OF HEATING: STOVES, FURNACES, FIRE-PLACES, STEAM AND HOT WATER.

It is presumed that every reader of this book will admit that good ventilation is a very desirable thing, and that we should pay at least as much attention to it as to the ornamentation of buildings. But we must also bear in mind another very important fact, viz., that in cold weather satisfactory heating is even more desirable and necessary, since without it the better the ventilation the louder will be the complaints. We may write and talk as much as we please about the horrors of foul air and the importance of good ventilation, but we shall never induce our audience to consent to sit in cold draughts and shiver for the sake of pure air, and in fact we would not do it ourselves.

We must therefore make sure first of having satisfactory heating arrangements in our building, and having done this must make the plan of ventilation correspond to the particular method of heating adopted, at least during the winter season. The methods of heating between which we may choose are the following, giving them in the order of frequency in which they probably occur in buildings designed by architects, viz., hot-air furnace, steam, fire-places, stoves, hot-water apparatus (low pressure), hot-water apparatus (Perkins' system).

The great majority of dwelling-houses in this country are heated by stoves, because this is the most economical method of heating, but architects do not have occasion to design many buildings of this kind, since they are usually constructed to sell or to rent by builders who are their own architects.

Next to the stove, the most economical means of warming an ordinary dwelling-house is a hot-air furnace. In the great majority of large public buildings, hospitals, etc., steam is employed, and still for the same reason—*i. e.*, because it is the cheapest. It is only in houses where the expense of maintenance is a matter of little or no consideration that fire-places are used, and even then they are almost always supplemented by some method of heating the incoming air by indirect radiation.

It is only where the first cost of the apparatus is a minor consideration, and where the cellars can be almost entirely given up to the heating apparatus, that hot water is used.

Before discussing the merits of these various methods, it is necessary to understand the essential difference between heating by direct or by indirect radiation. In direct radiation the heating apparatus is placed in the room or space to be warmed. This applies to fire-places, stoves, and coils or radiators filled with steam or hot water. The heat passes from the radiant body to the solid bodies or surfaces around, which absorb it, but this radiant heat does not raise the temperature of the air through which it passes. It is therefore possible by using direct radiant heat to keep a room comfortable, although the air in the room may be from five to ten degrees below the temperature of solid bodies in the room. This is almost always the case when the fire-place is used as the source of radiant heat. The great majority of writers on this subject state that radiant heat is preferable from a hygienic point of view, but the evidence for this is not entirely convincing. Several years ago I wrote as follows: "It certainly adds to comfort and health that the heating of the air inspired, beyond a temperature of about 50° F., should be accomplished in the lungs rather than previously by artificial means. It is possible that this depends upon the increased transpiration when cool air is breathed, and that this favors the removal of effete organic matter or of volatile organic bases. When air is heated, its capacity for taking up moisture rapidly increases. Air inhaled at 45° F. and expired at 95° F. will take up 50 per cent. more vapor than air inspired at 65° F., supposing the previous relative saturation to have been the same." When that sentence was penned, I thought I knew a great deal more than I am now inclined to think was the case, and I am not at present disposed to be at all dogmatic upon this point. I have carefully observed my own sensations in breathing air at a temperature of from 65° to 75° F. on bright, clear days in the spring and fall, and I now think that the temperature of the air inhaled, when this is between 45° and 70° F., is in itself a matter of small importance so far as either comfort or health is concerned.

I have not, however, been alone in this error, for it is strongly insisted on by one of the principal advocates of direct radiation. Mr. Lewis W. Leeds lays great stress on the discomfort produced by breathing air at a temperature of 70°, which he calls "detestable" and "miserable" stuff, and he thinks that the more one has of it the worse off he is. He would therefore use direct radiation by means of steam coils or radiators placed beneath the windows, and provides no special inlets for fresh air. In other words, he gives up ventilation practically, and devotes his attention to heating. By taking this course, one can undoubtedly secure the approval of the majority of clients—it secures comfort and is comparatively cheap; but on the whole it is not advisable to rely upon it in any room where a number of people are to be collected.

The majority of those who write on the beauties of warming by open fire-places in this country have had no experience of fire-place warming with the external temperature at 10° F., or lower. I have had such experience, and it was not pleasant. An open fire-place is a cheerful addition to other means of heating, but it is dangerous, troublesome, and difficult to regulate, and no one who can have a good furnace or steam or hot-water apparatus in his house in our northern climate will act wisely in relying upon fire-places altogether. Nevertheless, I strongly advise that a fire-place be provided in every room which is to be inhabited in a dwelling-house, but this is for purposes of ventilation rather than heating, as will be explained hereafter.

What is known as the Galton fire-place may, perhaps, be an exception to these remarks, for it makes provision for warming the fresh air to some extent, but it is much better suited to the English climate than to our own.

Some trials have been made in our small army hospitals of double fire-places, placed back to back and so arranged that the fresh air was introduced between them, and warmed before it escaped into the room. With anthracite coal these double ventilating fire-places worked very well when the external temperature was above 30° F., giving excellent ventilation and very fair heating; but when the external temperature was near zero, and when only wood or soft coal was available, it seemed as if the more fire was made the colder it got, since the incoming air was not sufficiently warmed, and at times it appeared as if the inmates might be frozen to death by their own fire-places.

There are a number of patent stoves, which act upon the principle of the ventilating fire-place, but the amount of air introduced and warmed by them is usually small. For small rooms, occupied by only one or two persons, they answer very well, but in a large room, containing many persons, it is extremely difficult, if not impossible, to secure a satisfactory introduction and distribution of fresh air by any form of stove placed in the room itself. The stove must be placed below the room to be warmed; in other words, it must be converted into a furnace. The great majority of hot-air furnaces as actually used are unsatisfactory, and special sources of danger to health, but this is not so much the fault of the furnaces themselves as of the manner in which they are set and adjusted. They are better than stoves in this respect, that satisfactory heating cannot be secured by them without the introduction of air into the room to be heated, but the air that is introduced by them is often of a very unsatisfactory quality.

If a building is to be heated by a hot-air furnace, the following points should be borne in mind in its selection and adjustment:

First.—In ninety-nine out of every hundred buildings in this country in which this method of heating is used, the furnace is too small. The result of this is, that in cold weather, in order to secure comfort, it is necessary to raise the radiating surface to a high temperature, often to a red heat. The contraction and expansion due to such great changes of temperature soon loosen the joints of furnaces built up of several pieces, and permit the escape of the gases of combustion into the fresh air supply. Of these gases, carbonic oxide and sulphurous acid are the most hurtful.

The sulphur compounds, when present in harmful quantity, are so perceptible to the smell and create irritation of the air passages to such an extent as to soon call attention to the evil and lead to attempts to remedy it. Carbonic oxide is odorless. When present in small quantities, it produces a peculiar feeling of discomfort, somewhat as if a tightly-fitting band were drawn around the head, increasing to a dull, persistent headache, with slight giddiness, languor and disinclination for either mental or physical exertion. This gas will pass through red-hot cast iron, and this fact is much insisted on by the manufacturers of wrought iron, soapstone or brick furnaces. The special danger on this account from a cast-iron furnace is probably extremely small; it is much more due to defective castings containing sand holes, or to badly-fitting joints.

As Mr. E. S. Philbrick has pointed out,* wrought-iron furnaces are by no means faultless as regards leakage, "for if often heated to redness they suffer such strains by the expansion and contraction which always accompanies heating and cooling, that the joints will be apt to fail, or other cracks open in a little time." Moreover, wrought iron oxidizes much more rapidly than cast iron, and will fail sooner from this cause. It may be safer when new, but is more perishable. Brick, clay or tile furnaces are not much used in this country. They take up much more room than iron furnaces, but have the advantage of giving a much larger heating surface at a comparatively low temperature.

Second.—As furnaces are usually set, there is no provision for mixing cool air with the heated air. The result of this is, that the air is delivered in the room at a high temperature—often at 140° F., and sometimes higher—and the only way to prevent the room from becoming too warm is to close the register, which, of course, shuts off the supply of fresh air. I shall have occasion to allude to this again in discussing the subject of moisture of the air.

Third.—The source of air supply to a furnace is often very unsatisfactory. Sometimes it is taken directly from the cellar itself, in which

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* See Material for Stoves, the *Sanitary Engineer*, Vol. III., page 3.

case it is almost sure to be contaminated with gases escaping from the furnace door, while the cellar itself contains decaying vegetables, slop buckets, and perhaps an empty bell trap, giving free communication with the sewer; or the air box from the outer air to the furnace passing through the cellar may have so many cracks and loose joints, that the cellar air finds an easy entrance to it. The fresh-air supply should not be brought in through an underground duct without taking special precautions to have it air-tight, and it should not pass across or near a drain or sewer.

As a rule, architects make no special provision for the fresh-air supply to a furnace, and the furnace setter is left to adjust this as best he can, the result being that he will often select that method which involves the least trouble and expense, but which also will give the least satisfactory result.

Fourth.—A furnace is usually placed near the centre of a building, the object being to have the flues conveying the heated air from it as short and with as rapid an ascent as possible. Horizontal flues for heated air are very undesirable, as the friction in them checks the current and involves loss of heat. The direction of the wind has a great influence on the action of hot-air flues, and for this reason it is better to place the furnace not in the centre, but toward that side of the house against which the winter winds blow most frequently and strongest. In our vicinity this will be toward the northwest. If a building of large area is to be warmed by furnace heat, it will be much better to use two or three furnaces distributed over the area than one large central one.

It is no part of my purpose to discuss the merits of the various patterns of furnaces now in the market, and I will only say in regard to them that those which have the fewest joints and the largest amount of radiating surface in proportion to the size of the fire box, are to be preferred—other things being equal—and that it is very poor economy to buy a furnace which is not large enough to furnish, in the coldest weather, all the heat required, without heating the fire pot to a red heat.

In this country nearly all large public buildings are heated by steam, and in preparing plans for such edifices our architects take it for granted that this method will be employed, unless specific directions to the contrary are given by the building authorities.

The cases in which hot water apparatus is used in such buildings are comparatively few, this form of heating in this country being for the most part confined to greenhouses.

The reasons why steam has thus obtained the preference over hot water are worth considering. As a rule, our architects give no attention to the details of heating apparatus, and prepare their plans without any special reference to such details, other than providing space and a chimney flue for the boiler, and other flues in the walls.

They rely for all details upon those firms who supply heating apparatus, and are therefore guided by their advice to a great extent in the selection of apparatus.

The firms which make a business of furnishing steam and hot water apparatus are comparatively few, for the business is one which requires large capital; but, few as they are, there are not one-fourth of them who employ a properly-educated engineer to prepare their plans and specifications, or to supervise the setting of their apparatus.

Now, it is very much easier to plan and set up a steam-heating apparatus which will work, than to do the same with a hot-water apparatus. Please observe that I say "which will work," and not "which will work properly, and be also the most economical as to construction and maintenance;" and I also omit in this connection all considerations as to the securing proper ventilation.

In a steam apparatus it is not necessary that the boiler shall be on a lower level than the heating surfaces, and much greater inequalities and more frequent alterations in the levels of the flow and return pipes are permissible than is the case with hot water. In a hot-water apparatus a mistake of a few inches in the height of a pipe may prevent the working of the whole system. In a steam apparatus the injurious effects of miscalculation as to areas of pipes or of radiating surface may, to a considerable extent, be overcome by increasing the pressure in the boiler, although at an undue expense for fuel, while this can only be done within very narrow limits in a hot-water apparatus.

As the radiating surfaces in steam heating are kept at a higher temperature than when hot water is used, the radiators may be made smaller and more compact, and thus be more convenient in some places than the larger hot water coils. It is also easier to "scamp" a steam heating job than a hot water one.

The very general use of steam as a source of power has made a large number of workmen familiar with the boilers and fittings required for its use, and these can be everywhere obtained without difficulty.

For all these reasons, in addition to the important one that the plant for a steam-heating apparatus is cheaper than for a hot water one, it has come to pass that there are but three or four firms in this country which recommend hot-water apparatus under any circumstances, or which are willing to undertake repairs or alterations in such apparatus. Hood states that "the first cost incurred for the erection of the two kinds of apparatus will differ but little when the work is done in an equally substantial manner; but the wear and tear and repairs of a hot-water apparatus will be less than that of a steam apparatus, as in the former there is absolutely nothing that can wear out except the boiler, while in a steam apparatus there are various things which constantly require attention and repair, in addition to the greater amount of wear in the steam boiler itself, caused by the large quantities of sediment which requires to be constantly removed."

The principal disadvantages of a steam-heating apparatus are as follows :

First.—It requires constant attention to keep up the supply of heat, for as soon as the production of steam in the boiler ceases the radiating surfaces cool rapidly. This is claimed as an advantage in the steam-heating apparatus for rooms that are to be occupied but a few hours each day, on the ground that it furnishes the heat only when it is actually wanted, and is, therefore, more economical than a hot-water apparatus, from which heat continues to radiate for several hours after the necessity for it has ceased. While this is true to a certain extent, it should be remembered that to secure comfort in cold weather the walls, floors, etc., of a room must be warmed to a certain point, and that heat must be expended in doing this whenever these surfaces are allowed to cool, so that the shutting off the supply of heat is by no means a clear gain.

Second.—Owing to the high temperature of steam radiators as compared with hot-water ones, it is more difficult with the former to regulate the supply of heat in accordance with the demands of our very variable climate without interfering with the amount of air supply. As steam-heating apparatus is usually arranged, the only way to diminish the heat is to either close the register, which cuts off the supply of fresh air, or to turn off the steam from the radiator, which will give an insufficient supply of heat. The result is, that the great majority of steam-heated rooms are, during many days in the year, too hot, and at the same time have an insufficient supply of fresh air, producing much the same kind of discomfort as an ordinary hot-air furnace, although somewhat less in degree. This evil can be remedied in two ways. The first is to arrange each set of radiators in several distinct sections, in each of which the flow of steam can be controlled independent of the others, so that when but little heat is required only one section need be used, and so on in proportion to the external temperature. This method, however, is practically applicable only in large establishments where there is an engineer, whose exclusive business it is to look after such matters, and also only where all the air supply for the building passes through a single duct.

I have seen one or two buildings where the radiators were thus adjusted, but upon inquiry found that no use was made of the means of controlling them.

The second mode of remedying the evil is to so arrange the air ducts and flues that by the movement of a valve the air can be at pleasure made to pass either wholly in contact with the radiating surfaces or wholly separate from them, or partly in one way and partly in the other, in such proportions as may be desired. By this method very excellent results may be secured, but it requires careful adjustment of the valves and flues and constant supervision.

Third.—A steam-heating apparatus is somewhat more dangerous than a hot-water one, but if it is set and managed with good ordinary intelligence the danger is very slight. The automatic adjustments are now so satisfactory in steam boilers for this class of work that an explosion is hardly possible, and the danger of fire from steam pipes is very small. Such danger, however, exists, and it should be remembered in carrying steam pipes on or near wooden surfaces.

The advantages and disadvantages of hot-water heating apparatus have been in part indicated in the above remarks on steam-heating apparatus. The temperature of the air warmed by hot-water apparatus is moderate, it being difficult to raise it above 100° F., with the temperature of the hot-water pipes at from 160° F. to 180° F. It requires also comparatively little attention to secure comfort, since the hot water continues to circulate for some time even after the fire is extinguished.

The use of water as a vehicle for the conveyance of heat has been long known, and much more has been published with regard to it than with regard to the use of steam for the same purpose. Yet, as I have before stated, it is comparatively little used in this country except for heating greenhouses, where constancy and regularity of temperature are so important that no other method will produce as good results.

The most important work on heating by hot water is the practical treatise by Charles Hood, on Warming Buildings by Hot Water, Steam and Hot Air, on Ventilation, etc., the fifth edition of which, published in 1879, is now before me.

The principal objection to this book as a practical guide for work in this country is that it has too exclusive reference to the demands of the English climate, and that hot-water apparatus constructed in accordance with its formula and set up in New England would be found to give an insufficient supply of heat.

Mr. Hood bases all his calculations as to amount of radiating surface required upon the assumption that these radiators should be composed of cast-iron pipe four inches in diameter. Those who have had most experience, and attained the greatest success with hot-water apparatus in this country, prefer three-inch pipe, and use much more of it than Hood's formula calls for.

The advantage which the smaller size of pipe presents is that it has a larger radiating surface in proportion to the amount of water contained, and therefore insures a quicker circulation. It will not do to use less than three-inch pipes in most of the radiators, because the friction increases rapidly with the reduction of the diameter of the pipe, and thus impedes the circulation and diminishes the effect. Where it is specially important to guard against the effects of negligence in firing, as in a greenhouse, and where, therefore, a large body of hot water is needed as a sort of storehouse of heat, four-inch pipes may be usefully employed, but not otherwise.

It will be found convenient to remember in calculations that, including sockets, etc., 100 feet run of three-inch pipe give about 100 square feet of radiating surface.

Mr. Hood's calculations as to the amount of air to be warmed are based on a supply of from three and half to five cubic feet per minute for each person in habitable rooms, which is hardly one-tenth of the amount required for the preservation of health and comfort. He also allows one and a quarter cubic feet of air per minute for each square foot of glass which the building contains, and having thus calculated the quantity of air to be heated per minute, he gives the following rule for finding the amount of pipe required to heat it:

"*Rule:* Multiply 125 by the difference between the temperature at which the room is purposed to be kept when at its maximum, and the temperature of the external air, and divide this product by the difference between the temperature of the pipes and proposed temperature of the room, then the quotient thus obtained, when multiplied by the number of cubic feet of air to be warmed per minute, and this product divided by 222 will give the number of feet in length of pipe, four inches diameter, which will produce the desired effect."

This rule depends upon the fact, determined by experiment, that one foot of four-inch pipe will heat 222 cubic feet of air one degree per minute, when the difference between the temperature of the pipe and the air is 125°. To apply it to three-inch pipe, the quantity should be increased by one-third.

From this it would follow that to heat 1,000 cubic feet of air per minute, using for this purpose three-inch pipe at the temperature of 180° F., and supposing the temperature of the external air to be at zero F., there would be required to maintain the room at the following temperatures, the amount of pipe set underneath each, viz.:

Temperature at which room is to be kept	55°	60°	65°	70°	75°
Number of feet of 3-in. pipe required for each 1,000 feet of air per minute supplied	330	375	424	477	536

Those who furnish hot-water apparatus very rarely calculate the amount of radiating surface with reference to the amount of air to be supplied. They proportion the amount of radiating surface to the cubic space to be heated, according to certain empirical formula, in which usually the question of ventilation is not taken into account.

For example, to heat churches and large public rooms, Hood allows one foot of four-inch pipe to each 200 cubic feet of space; that is, five feet per 1,000 cubic feet. For dwellings he allows 14 feet per 1,000; for schools and lecture-rooms, from six to seven feet, and for greenhouses 35 feet per thousand, and says that these amounts have been determined by actual trial.

Mr. Anderson, in a valuable paper on the emission of heat by hot water pipes, concludes that for ordinary dwelling-houses one square foot of surface is necessary to every 65 cubic feet, and in a greenhouse one square foot to every 24 cubic feet. These figures are based on data collected by him, a specimen of which is given in the accompanying table.

I give this table not only because of the data contained in it, but because it shows the kind of information which is needed to put this subject of heating on a scientific basis.

There is, however, one very important defect in the table, viz., it gives us no information as to the amount of air which passed over the heating surface in a given time. In the school buildings there seems to have been no ventilation at all. It does not seem to have occurred to Mr. Anderson that ventilation is of any importance in connection with heating problems. He remarks that "the heating surface necessary to warm a given building depends on a variety of circumstances—on geographical position, whether the house stands high and exposed or low and sheltered, and whether the average winter temperature is high or low; on the thickness and material of walls; on the area and construction of windows, and so forth." All this is true so far as it goes, but the ventilation is more important than any of the points he has named, and it is curious to see how totally he ignores it.

DESCRIPTION OF BUILDING OR ROOM.	Approximate working temperature of pipes.	Cubic feet of air contained.	External cubic capacity.	Area of heating surface.	Cubic feet to 1 square foot of heating surface.		Cubic feet of air to 1 square foot of heating surface reduced to 160°.	Area of walls and ceilings.	Number of square feet of wall surface to 1 square foot of heating.	Area of windows.	Remarks.
					Air.	Total external capacity.					
LESNEY HOUSE, ERITH, KENT.	°			sq. ft.				sq. ft.		sq. ft.	
The whole house is warmed by hot water, more especially the passages, which in the coldest weather can be maintained at 60°. The rooms all open into the passages. The house stands 150 feet above the river, and is much exposed.											
STUDY.—Bow window to the east. Hot-water pipes under window-seats, with three openings 7 inches by 4½ inches, covered by perforated zinc, through the walls to admit external air through coils. Coils concealed by open cast-iron work; constant current up the chimney. Only one external wall, namely, the bow window	160	3,329	......	83.0	40.0	......	40.0	1,098	13.2	96	Excess of heating power.
DINING-ROOM.—Bow window facing to the north, with coils in all respects as in the study. Another window faces to the west. Two external walls	"	5,386	......	83.0	65.0	......	6.50	1,481	17.8	118	Sufficient heating power.
BATH-ROOM.—One window, facing west; group of pipes placed against inner wall opposite window; no communication with the external air; open chimney; one external wall	"	1,072	......	53.3	20.1	......	20.1	525	9.9	18	Great excess of heating power.
ERITH PUBLIC ELEMENTARY SCHOOLS.											
One story brick buildings, not plastered inside, stand near the river, and sheltered by surrounding houses, the roofs ceiled up to the collar tie. The coils of pipes are quite open, and placed near the walls, most of which are external:											
Boys' school	"	24,917	29,465	326.0	76.4	90.4	76.0	5,213	16.0	342	Only just heating surface enough.
Girls' school	"	26,257	32,890	325.0	80.8	101.5	80.8	4,409	13.6	342	Hardly sufficient heating power.
Infants' school, total	"	37,195	41,350	442.0	84.1	93.8	84.1	5,198	11.7	432	Insufficiently heated.
Class-rooms—A	"	5,206	"	51.0	102.0	"	102.0	830	16.2		These rooms are too cold for the comfort of the children.
" " B	"	4,932	"	50.0	98.6	"	98.6	830	16.6		
" " Babies' south aspect	"	6,544	"	83.0	78.8	"	78.8	1,230	14.8		Barely sufficiently heated

CHAPTER V.

SCHEDULING FOR VENTILATION PLANS—POSITION OF FLUES AND REGISTERS—MEANS OF REMOVING DUST—MOISTURE, AND PLANS FOR SUPPLYING IT.

THE arrangement of the heating and ventilation of a large building requires, in order to obtain the best results, an examination of each room in the building with reference to its size, uses, number of occupants, and exposure. In order to do this methodically the rooms on each floor should be numbered in regular order, and then scheduled, the floor being designated by letters of the alphabet. B 7, then, indicates room No. 7 on the second floor, and this mark can be placed on the plans on all flues connected with this room.

The schedule should show for each room its length, breadth and height, cubic capacity, area of external wall, amount of window surface, exposure or frontage, purpose or use, and number of occupants to be provided for. Having these data the next step is to compute the maximum amount of air supply which it will require in cold weather, and from this to calculate the area of the flues and registers, and the amount of heating surface which will be needed to furnish this air supply. The area of the fresh-air registers will depend somewhat upon the location in the room at which the air is to be introduced, and this location must be determined by the following considerations :

First.—The register must be in such a position and of such a size that the requisite amount of air can be introduced through it without causing currents of air of such velocity as will cause discomfort to the occupants of the room. The only difficulty in this respect occurs in rooms occupied by a number of persons, such as assembly and school rooms, churches, theatres, hospitals, etc. Under such circumstances it is sometimes very difficult to so locate the fresh-air registers that the currents therefrom will not be unpleasantly perceptible if they are rapid, and it then becomes necessary to make these registers of such an area that the velocity of the inflowing air need not exceed 1½ feet per second to secure the introduction of an amount sufficient for both warming and ventilation. When the registers are so situated that the currents from them will produce no discomfort they may be made smaller. For example, if it be determined to introduce the fresh air directly through a perforated floor in an assembly room, the total area of openings should be at least 100 square inches for each occupant, while the area of register openings need not be more than 40 square inches for each occupant if they are placed near the ceiling.

Second.—Taking it for granted that the fresh air is to be warmed in cold weather before it is brought into the room, its registers must not be placed below the foul-air registers, unless the former are scattered all over the floor of the room. The reason for this is, that direct currents between the inflow and outflow registers are easily established when the latter are above the former, and in such case little change is effected in the great mass of the air in the room.

Third.—Flues of proper size cannot usually be placed in thin walls, such as ordinary interior partitions. A flue measuring less than five inches in its smallest diameter is of little use. Fortunately, in ordinary dwelling-houses, where this difficulty of thin partition walls is greatest, the precise location of fresh and foul-air flues is of minor importance so long as the precaution advised in the preceding section be observed.

Fourth.—Fresh-air registers should not be placed in a floor so as to be flush with its surface, because dust and dirt will fall into the flues and be returned to a certain extent in the column of ascending air. Such registers are also a fruitful source of loss of small articles. It is always possible to continue the flue upward into a step or seat, and then place the register in the side of this.

There is less objection to placing foul-air registers in the floor; but even this should be avoided, unless the openings are covered by some article of furniture, as for instance in a hospital ward, where a good position for the foul-air registers is in the floor beneath each bed; and even then the register should not be flush with the floor, but rise an inch or two above its surface.

Fifth.—In dwelling-houses and buildings of moderate size it is economical to centralize the heating apparatus as much as possible, keeping the fresh-air flues in inner walls; but it is not easy by this method to secure sufficient warmth in the vicinity of windows, especially on the side most exposed to the winter winds.

On the other hand, hot-air flues should not be placed in outer walls, unless these are thick and substantial, and even then it will be good economy to make the flue of terra cotta or galvanized iron, so set as to leave an air space of an inch or two on the outer side. For rooms on the floor immediately above the radiators, it is not necessary to place flues in the walls in order to bring the registers under or near the windows, which is their best place so far as heating is concerned. Foul-air flues should not be placed in outer walls, unless they are to be carried downward and to have some means of aspiration connected with them.

Sixth.—General Morin, and the majority of modern French engineers, advise that the place of introduction of fresh air shall be near the ceiling, in order to avoid unpleasant currents, while the discharge openings, on the contrary, should be near the floor. The introduction of warm air near the ceiling, in order to prevent disagreeable currents, is not absolutely essential, for such currents can be avoided, as above explained, by making the registers of proper size; and to secure comfort in cold weather, it is necessary, on this plan, that the air shall be introduced at a temperature several degrees higher than is required if it be admitted at a lower level.

The proper position of the foul-air registers depends on the purpose of the room and on the season. During cold weather, in the majority of cases they should be near the level of the floor, to secure a satisfactory distribution of the air with the least expense. In large assembly halls, however, and especially where it is desired to provide for respiration air as pure as possible, instead of foul air diluted to a certain standard, the discharge openings should be above.

Seventh.—In order to secure a thorough distribution of the incoming air, it is usually recommended that the discharge openings should be in the side of the room opposite to that in which the fresh-air openings are placed, and as far as possible from them.

In all dwelling-houses, however, and in rooms not having windows on opposite sides nor containing a sufficient number of occupants to exercise any special influence on the temperature, good ventilation will be secured by placing the fresh warm-air openings on an inner wall, and the discharge openings in the same wall at the same or a lower level. This is the arrangement in most dwellings heated by indirect radiation, the fresh-air register being in the side of the chimney near the floor, and the foul air passing out through perforated fireboards on the same level a few feet away. The result is the establishment of a circulation from the fresh-air opening upward and along the ceiling to the outer walls and windows, thence down the wall to the floor, and along the floor to the discharge.

But when we come to deal with rooms having a large floor area in proportion to the height, and containing fifty or more persons, whose heat production is a factor that must be taken into consideration, there is some danger by this method that there will be an unsatisfactory distribution of the fresh air when the temperature of the external air is not below 50° F.

We are much in need of full and reliable reports of the results obtained by careful experiment with apparatus arranged in this manner. Experiments with models are, however, not of much value in these questions; what we want are experiments with the apparatus itself when it is in actual operation.

In preparing plans for the heating and ventilation of buildings in large cities, the architect or engineer is sometimes called on to provide for the removal of particles of soot and dust of various kinds suspended in the air, or, in other words, for the filtration of the air. So far as healthy persons are concerned, this matter of air filtration is a point of theoretical interest rather than of practical value, and if we can give to such persons a sufficient supply of such air as they will breathe when walking in the street, we shall have done quite as much as will usually be required.

In buildings or rooms containing sick persons, or works of art, books in fine bindings, or other things to which dust will be injurious, it will be well to provide means of removing the dust from the incoming air. If the building be heated by any form of indirect radiation, and the air supply for this purpose enters through a single duct, this can be easily done by using strainers of coarse cotton cloth, or, better still, of thin layers of cotton batting inclosed in wire frames, as is done in Mr. Dickerson's house in New York City. The chief points to be borne in mind in arranging such a system of filters are, first, that they form a decided obstacle to the entrance of air, as they give rise to much friction, and hence, that their area must be six or eight times that of the delivery flues; and second, that the filters must be renewed as often as they become clogged and foul.

In public buildings attempts are sometimes made to accomplish this filtration, as well as to secure moisture and coolness, by passing the air through sprays or thin sheets of water. Where it is desirable to filter the air for a single room, as, for instance, in a case of sickness, this can be done by placing a large frame before the register, covered with two or three layers of coarse cotton cloth. Slices of coarse sponge have also been recommended for this purpose, but they obstruct the air too much. If the sponge be moistened and hung in front of the register it will act to some extent as a filter, but mainly as a source of moisture to the air, and as a means of lowering its temperature by the rapid evaporation produced.

In living rooms, heated by a hot-air furnace or by indirect radiation by steam, the use of a large, coarse, moist sponge in front of the register will often be a source of great comfort. Vessels of porous clay, through which water percolates rapidly, are used for the same purposes.

This brings us to the question of attempting to regulate the moisture of the air in connection with apparatus for heating and ventilation. The precise influence which either the absolute or the relative amount of moisture in air has upon health is uncertain, for habit enables man to undergo great variations in this respect without marked ill effect. Simple dryness of the air certainly is not injurious to health. At Fort Yuma, during the months of April, May and June, when no rain falls, the average temperature day and night is 90° F., and the air is so dry that the skin becomes dry and hard, the hair crisp, and furniture falls to pieces. Newspapers must be handled carefully or they will break, and a No. 2 Faber's pencil leaves no more trace on paper than a piece of anthracite. Yet this may go on, even with a temperature of 100° F., for weeks in succession, and there will be no additional sickness.

Dr. Wyman states that the Harmattan, a wind which blows from the scorching sands of Africa, drying the branches of trees, cracking doors and furniture, and drying the eyes, lips and throat, so that they are painful, is not an unhealthy wind; on the contrary, its first breath cures intermittent fevers, and malarial affections disappear as if by enchantment. A dry air, with a uniform temperature makes a healthy climate, as in New Mexico.

When we turn to artificial climates, we find that in our houses in winter, with the external air at 32° F., the percentage of moisture is often between 30 and 40 without producing any discomfort.

There can be no better illustration of this than the results obtained by Dr. Cowles in the Boston City Hospital, and published by him in the report of the Massachusetts State Board of Health for 1879.

He says: "I believe that no discomfort has been felt or ill effects produced from the low relative humidity, even on the occasions when there was only fifteen to twenty-one per cent. of saturation. According to Dr. De Chaumont, so great dryness is inconsistent with a healthful condition of the atmosphere. Certainly, in this ward there is uniformly observed a remarkable absence of complaint of any kind that can be ascribed to the condition of the air, and a peculiar feeling of its freshness and purity is frequently spoken of by those who enter the room."

It is evident, therefore, that it is not necessary to supply moisture enough to heated air to bring the percentage up to 70. It is also to be noted that it will take about the same amount of fuel, or, in other words, will cost as much to furnish this percentage of moisture to air heated from 32° F. to 70° F., as it does to heat the air. Moreover, in a room properly ventilated under such circumstances, it would be practically almost impossible to maintain such a percentage of moisture, owing to the great rapidity with which the vapor of water diffuses in such dry air and the condensation which would occur on windows and thin outer walls. This whole subject has been well discussed by Mr. Robert Briggs, in a paper entitled, "On the Relation of Moisture in Air to Health and Comfort," published in the *Journal of the Franklin Institute* for 1878, and to this I would refer for further details.

The effects produced in air by artificial heat, and which by some are supposed to be connected with insufficient moisture, are important, and merit more study than they have yet received.

Dr. Ure describes the effects of the use of highly-heated cockle stoves to be tension or fullness of the head, flushings of the countenance, frequent confusion of ideas, coldness of the extremities, and feeble pulse. Hood confirms this, and states that he examined a school heated in the same manner, and found it to be so pernicious to the health of the children that they occasionally dropped off their seats in fainting fits. He goes on to say that "these pernicious effects, although generally in a somewhat less degree, always result from the use of intensely heated

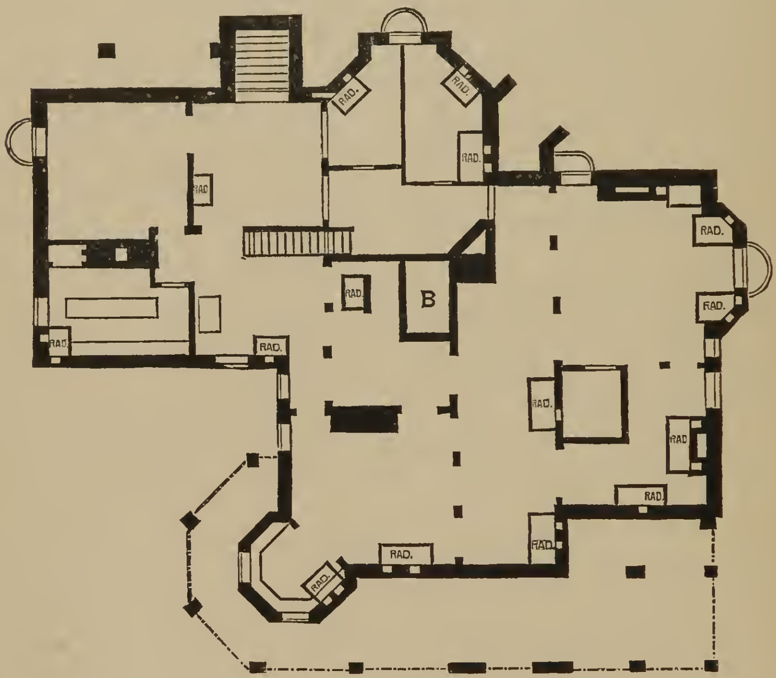

FIGURE 3.—CELLAR PLAN OF SUBURBAN RESIDENCE.—(See page 64.)
B.—Boiler. | *Rad.*—Radiators.

metallic surfaces. They are, however, much modified if the air is tempered by the evaporation of water. In Russia and Sweden, the Apennines, and other places where close stoves are used, an earthen vessel of water is always placed on the stove for this purpose, and greatly mitigates the oppressive effects which would otherwise be experienced. The dessicating power of the air increases with the temperature to a very great extent. Air at 32° contains, when saturated with moisture, $\frac{1}{160}$ of its weight of water; at 59° it contains $\frac{1}{80}$; at 86° it contains $\frac{1}{40}$; its capacity for moisture being doubled by each increase of 27° F.

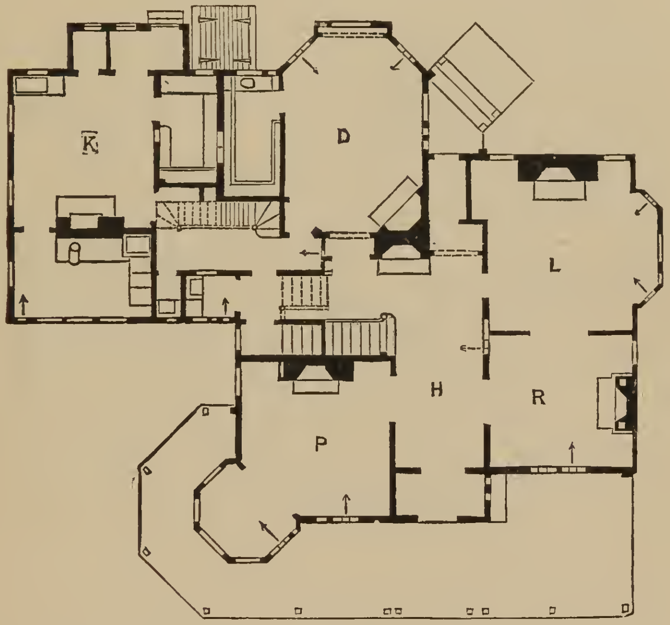

Figure 4.—FIRST FLOOR PLAN OF SUBURBAN RESIDENCE.—(See page 64.)

D.—Dining-Room.
K.—Kitchen.
L.—Library.
R.—Reception-Room.
P.—Parlor.
H.—Hall.

The *arrows* show position of Registers.

Of the reality of the effects referred to by Dr. Ure and Mr. Hood, as resulting, in some cases at all events, from heating air intended for respiration to a high temperature, there is no doubt; but that these effects are especially connected with the dryness of the air is not probable.

English writers usually state that, in order to secure health and comfort, the relative saturation with moisture of air to be respired should be from 65 to 75 per cent. Mr. Hood says that, "in rooms artificially heated, the most healthy state of the atmosphere will be obtained when the dew point of the air is not less than 10° nor more than 20° F. lower than the temperature of the room." Dr. De Chaumont states that for England the difference between the wet and dry bulb thermometers ought not to be less than 4° nor more than 5°, and that the percentage of humidity should not exceed .75, while Hood declares that we should endeavor to maintain in artificially heated rooms 82 per cent. of moisture. There is little doubt that De Chaumont is more nearly correct than Hood, so far as the English climate is concerned, but none of these figures will apply in the United States, as has been shown above.

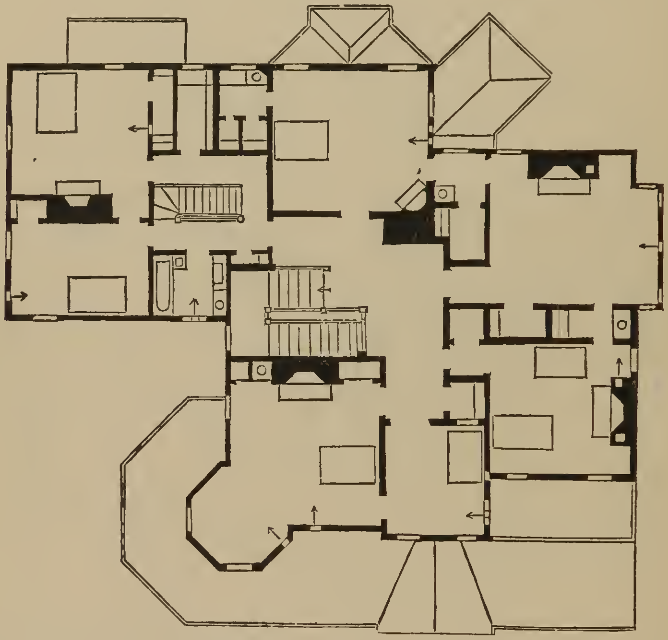

FIGURE 5.—SECOND STORY PLAN OF SUBURBAN RESIDENCE.—(See page 64.

The *arrows* show position of Registers.

But if it is not the dryness of the air which causes the disagreeable sensations, whose frequency in furnace and steam-heated rooms no one can deny, what is it?

My answer is, that it is no single cause, but a combination of a number of causes. The first and most important is the want of sufficient fresh air to insure satisfactory ventilation. The amount of air required for this purpose, if admitted after passing through the heating chamber of an ordinary furnace, would soon make the room insufferably hot, for on a cold day its temperature from the common forms of apparatus will average 180° F. To prevent this, the register is usually partially or entirely closed as soon as the room becomes unpleasantly warm, and the fresh air is thus shut off as well as the heat.

The second cause is the contamination of the fresh heated air by gases from the furnace, and especially by carbonic oxide. This will be found to be the chief trouble in those cases where a dull, persistent headache, with the feeling as if an iron band were bound around the head, is produced, or in such cases as those mentioned by Ure and Hood.

From hot-air furnaces these gases pass mainly at the joints, and the more joints a furnace has the worse it is in this respect.

A very common cause of impurity in air heated either directly by furnaces or indirectly by steam or hot water, when the furnace is in the cellar, is leakage from the cellar into the cold-air flues or chambers. Brick piers, inclosing coils or radiators, are quite pervious to air, and the pipes or box flues used to bring fresh air to the heating surfaces leak very decidedly in the majority of cases.

A very common method used by servants for diminishing heat is to open the furnace door, and at the same time to obstruct the draught below. This gives rise to large volumes of carbonic oxide, some of which will almost assuredly escape into the cellar, and it requires the presence of but a very small percentage of this gas to produce bad results.

The last cause of discomfort which I need mention here, is overheating in rooms which are occupied by a number of persons. In personal inspections in public offices I have usually found the temperature between 75° and 80° F., to suit the sensations of the older and feeble clerks.

In the preceding chapters the general principles which should guide the architect in arranging the heating and ventilation of a building, or at least in providing spaces and flues in his plans sufficient for the purposes of the sanitary engineer, have been briefly stated. Let us now consider some of the special applications of these principles in actual practice, and for this purpose we may take first a building in which the ventilation part of the problem is comparatively simple and easy, while the heating part is especially difficult. Such a building would be one in which the area of external surface is large in proportion to cubic contents, which is in an exposed situation, and whose occupants must be made comfortable at all times.

A private residence in a suburb of one of our northern cities, on an elevated site commanding a fine view of the surrounding country, and unprotected by neighboring buildings, hills, trees, etc., would be a building of this kind, and Messrs. Cabot and Chandler, architects, of Boston, have been kind enough to furnish me with copies of plans for such a dwelling, three of which are here reproduced.

The range of external temperature will in this case be from zero to 100° F., and the prevailing winds are from the southwest in summer, and from the northeast and northwest in winter, when they are sometimes strong and persistent for several days, with the temperature below the freezing point.

The external surface of the house is broken by projecting bays, which give it a much greater extent in proportion to the cubic space to be warmed than is usual, even in country residences, while the rooms on the main front of the building facing the cold, north winds, present special difficulties, so far as securing a comfortable temperature at all times is concerned.

In a building of this size and character it will be true economy to use some form of central heating apparatus. Neither fire-places nor stoves merit consideration as the principal means of heating. No form of hot-air furnace is advisable under the circumstances ; it would, in fact, require several furnaces if this form of heating is to be employed ; either a hot-water or a low-pressure steam apparatus should be used. The fire-places in each room will provide ample ventilation for the probable number of occupants, and this ventilation in cold weather is certain to be secured by the amount of fresh warm air which must be introduced to maintain a comfortable temperature. The most important question to be decided in this case is as to whether the radiators and hot-air flues shall be concentrated into one or two groups near the centre of the building, or whether they shall be placed against and in the outer walls. The latter arrangement is shown in Figures 3, 4 and 5.

In Figures 6, 7 and 8 are given three floor plans of the same building, showing all the radiators concentrated into two groups near the centre of the building, and all the fresh warm-air flues opening in inside walls. The arrangement of flues and radiators in these and the preceding plans has been made by Mr. C. W. Newton, of Baltimore, who has had much practical experience in laying out such work.

The difference in cost between these two plans would be about 25 per cent. in favor of the latter, or centralized method. The absolute cost in either case will depend upon whether the amount of radiating surface is to be sufficient to make the house thoroughly comfortable in the coldest weather and during cold northeast storms, or whether such surface is to be calculated only for temperatures about the freezing point, that is, for the average demand, relying upon the fire-places and grates as auxiliary sources of heat on those days when the apparatus in the cellar is insufficient. If the latter alternative be adopted, the cost of the apparatus can be reduced very much, yet to do so will be a doubtful economy.

Unless the cost be made a serious objection by the proprietor, I should advise the adoption of the peripheral plan of heating, as shown in Figures 3, 4 and 5. But if the house is to be placed in a sheltered situation, or to be built in the vicinity of Baltimore, or further south, or if it were to be built in England, I should advise the centralized plan.

Figure 6.—CELLAR PLAN OF SUBURBAN HOUSE.—(See page 64.)

Q.—Cellar.
R.—Vegetable Store-Room.
S.—Stairs to Area.
W.—Entrance to Coal Vault.
X.—Heating Coils.

The general principle of centralizing the heating apparatus is that adopted by Drs. Drysdale and Hayward in the plans which they give in their book on "Health and Comfort in House Building." After stating that no direct admission of the external air into the rooms of a house can be borne during at least eight months of the year, and that no plan of ventilation, applicable only to single rooms, can supersede the necessity of a general plan for the whole house, they say, that to prevent waste of heat "care should be taken in the original plan of the house to have a central hall, corridor, lobby, fresh-air chamber, or vestibule, separate from the stairs-lobby, and into which no outer door should open. The back door should open into the scullery or kitchen, or some other room in which it is the interest of the servants, for their own comfort, to keep it shut. The front door should open into a lobby or vestibule to which there is a separate access from the servants' department, without their going through the central hall of the house proper."

From this central hall, kept permanently warm and serving as a warm-air distributing chamber, they direct that the doors of all rooms should open, and they bring the air from this hall into the several rooms near the top of the room through the cornice. The plans of houses given in this work will be found interesting and suggestive.

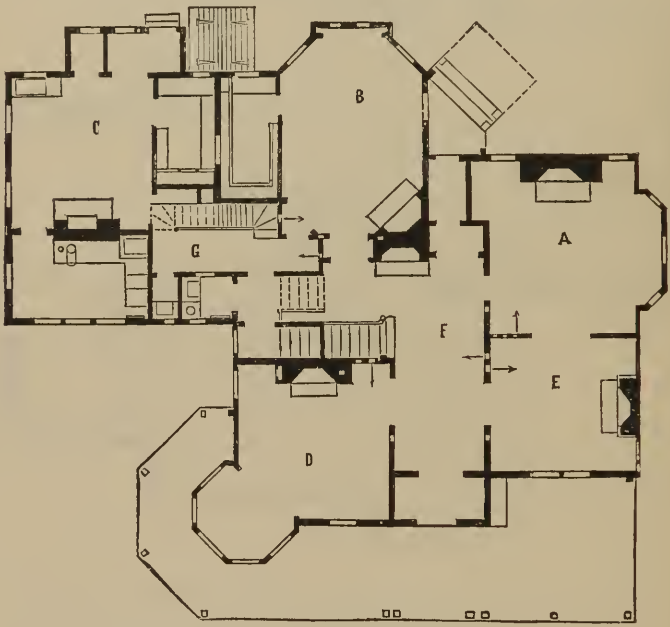

FIGURE 7.—FIRST FLOOR PLAN OF SUBURBAN HOUSE.—(See page 64.)

A.—Library.
B.—Dining-Room.
C.—Kitchen.
D.—Parlor.
E.—Reception-Room.
F. and G.—Hall.

The removal of the foul air in these houses is effected by the waste heat of the kitchen fire, the air passing from each room at the ceiling to a foul-air chamber, and thence down and behind the kitchen chimney fire, from which point it passes up the chimney.

Let us now take, as a contrast to buildings of this kind, in which the heating is the most difficult part of the problem, a private residence of the better class, situated in a block in one of our large cities. Such a house will not be exposed to cold, bleak winds, and is in the most favorable conditions for heating, being exposed to the external air on two sides only.

On the other hand, its ventilation is more likely to be unsatisfactory, and will require more attention than will that of the country house.

FIGURE 8.—SECOND FLOOR PLAN OF SUBURBAN HOUSE.—(See page 64.)
H, *I*, *J*, *K*.—Chambers. *L*, *M*.—Halls. *N*, *O*, *P*.—Chambers.

The external air is not as pure; it contains dust of all kinds—soot, street sweepings, etc.; the air in the house is liable to special contaminations by leakage of gas into its cellar or basement; and it has happened that offensive gases have passed directly through party walls from one dwelling to another. The great cost of the ground leads to gaining space by increase in height, while every additional story adds to the cost and difficulty of providing equable and satisfactory heating and ventilation.

In a tall building, where all the rooms open directly into the staircase hall, and no provision is made for dividing this hall and staircase upon the several stories, so as to prevent the free communication of the air in it, the result is that the hall is liable, by leakage from above, or by the opening of a window in the upper story, to become a ventilating shaft, which will interfere with the proper working of the chimney or ventilating flues within the rooms. In such buildings in cold weather it will often be found that the upper stories have a temperature several degrees higher than the lower, and, if the house be heated by indirect radiation, that to secure comfort in the parlor and dining-room, the bedrooms are made too hot. It is especially difficult in such houses to prevent the odors and steam from the kitchen and laundry, which are usually placed in the basement, from being unpleasantly perceptible in the halls and upper stories.

On the other hand, both the fresh and the foul-air flues will be, for the most part, on inner walls, where their operation is not liable to be interfered with by winds or cold.

One method of arranging such a city dwelling is shown in the accompanying illustration (Fig. 9), which shows the floor plans of the residence of Mr. E. N. Dickerson, of New York City, who has kindly given permission for their publication, and has also furnished some interesting information as to the results obtained. The plans of the first and fourth floors are not given, as they are not necessary to an understanding of the system of heating.

The essential feature of this house is the central hall, occupying the whole width of the building, and well lighted from above by a large skylight.

It will be seen that a part of this hall is cut off for a private or back staircase and a lift, and that upon the parlor and upper floors it forms a part of the main suite of rooms. At the skylight is an opening having an area of 2½ square feet, always open, and when the heating apparatus is in operation there is a steady upward current from the basement through the staircase well, which is just perceptible to the hand, being between one and two feet per second.

The plans are, for the most part, self-explanatory.

The heating is by steam at a very low pressure, the boiler being entirely out of the house under the front pavement. The heating coils are divided into three groups, as shown in basement plan, having in all about 2,200 feet of 1-inch pipe. Before reaching the coils, the incoming air is filtered by being drawn through sheets of cotton wadding placed between wire frames. The results are stated by Mr. Dickerson to be extremely satisfactory. The greater part of the ventilation is effected by the central hall and skylight. The amount of air supply is very large, and no difficulty has been experienced in having open fires in open fire-places when desired. The chandeliers in the parlor and dining-room contribute to the ventilation, as shown on the plans, and it is stated that twenty persons can smoke in the dining-room without causing the least accumulation of smoke. Similar ventilation is supplied to the chandeliers in the library and other rooms upon the third floor.

Of course the flues with which these chandeliers communicate must pull against the great central staircase flue, but the results reported by Mr. Dickerson are so satisfactory that it is evident that the amount of air supply is so large as to be ample for all the outlets. The amount of fuel used must be relatively large—that is, large as compared with what would be required to heat the same house with the same apparatus if only the ordinary amount of ventilation were provided. It would be a matter of considerable practical interest if a series of anemometrical

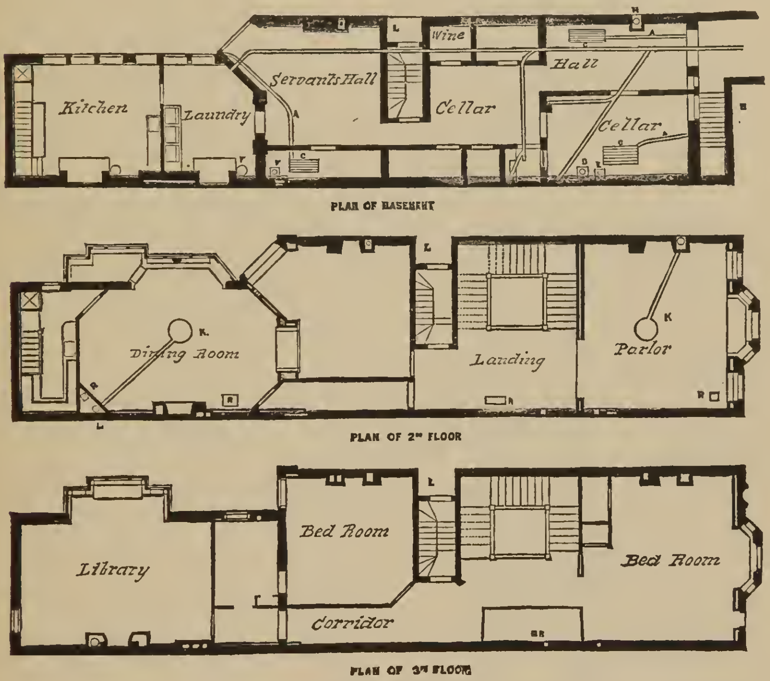

FIGURE 9.—DESCRIPTION OF PLANS OF MR. E. N. DICKERSON'S RESIDENCE, NEW YORK CITY.

A.—Fresh-air inlet flues.
B.—Boiler, separated from house by open area.
C.—Heating Coils.
D.—Flue to hall and 2d story.
E.—Flue to 3d story bed-room.
F.—Flue to dining-room.
K.—Chandelier with vent to convey products of gas combustion.
L.—Kitchen heated flue.
H.—Chimney of boilers with cast iron flue into which gas lights are ventilated.
R.—Registers.
B R.—Bath-Room.

observations as to the amount of air actually passing through the heating coils during a week of cold weather could be made, together with observations of the external and internal temperatures, and a statement of the amount of fuel actually consumed.

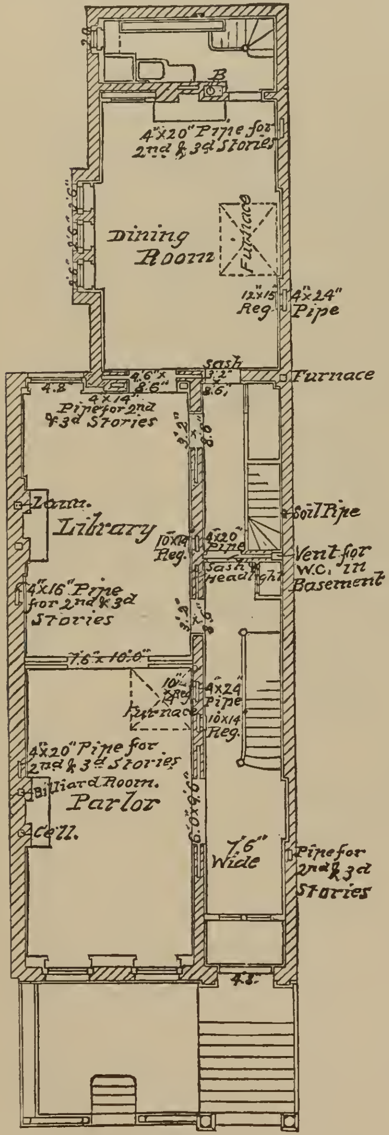

FIGURE 10.

Figure 10 is a plan of another city house in a block. This is the common arrangement in such rows of dwellings, the characteristic feature being a narrow, rather dark hall extending from front to rear, on one side of the building. This hall contains the stairway, and in many cases a water closet. The annexed illustration gives the main floor plan of such a residence, which is superior to the average in size.

This house is heated by two furnaces, the locations of which are shown in dotted outline, and this mode of heating will prove entirely satisfactory, provided only that the fresh-air ducts and the heating surfaces are made large enough to prevent the possibility of the air as it leaves these surfaces having a higher temperature than 140° Fahrenheit.

The best way to arrange the ventilation of such a house as this would be upon the principles indicated by Drysdale and Haywood, as indicated in the last chapter, and for this purpose more space should be given in connection with the kitchen chimney.

With fire-places and separate flues therefrom in all living rooms, there will be little trouble about ventilation at all times, when the external temperature is below 40° F., for there will then be a steady current up each flue, provided the fresh-air supply be sufficient, which last must be the case if the room is satisfactorily warmed. The special difficulty in ventilation in a house like this, and one of the chief dangers to health, is due to the pollution of the air of the hall and sleeping-rooms from the plumbing arrangements.

With a dark water closet near the centre of the house, it is necessary to take special precautions to secure its satisfactory condition at all times. The methods of doing this, so far as plumbing work is concerned, do not fall within the scope of this work, but I must insist upon the necessity of a satisfactory ventilation of the closet itself. The surest mode of effecting this is by a shaft passing up and through the roof and suitably capped, as I shall hereafter explain, in which shaft a steady aspirating force is to be exerted by means of a gas jet, which may at the same time serve to light the closet.

This shaft should take its air supply from beneath the seat of the closet, and it will be well to place in it the soil pipe, which I take for granted is also to be continued up through the roof.

The area of this ventilating shaft should be about 30 square inches, if it passes straight up without bends or corners and does not contain the soil pipe. The portion of the flue within the closet can be best constructed of galvanized iron, and should be fitted as a lantern at the point where the gas jet is brought into it. This gas jet should have a stop so arranged that it can never be turned entirely out without the use of tools, although it may be reduced to a very small flame.

The warmer the weather, especially if it is still, the more heat will be needed from the jet to secure satisfactory ventilation. The air supply for the closet should be taken from the hall through a transom or louvred openings in the top of the door, thus making the closet the bottom of an air shaft for ventilating the hall.

I wish it to be clearly understood that the arrangement is recommended only for those houses which have their drainage arranged as advised by the *Sanitary Engineer*, and where the closet is not against an outside wall. The use of the gas jet is advised, because it is, upon the whole, the cheapest method of securing a constant upward current under such circumstances. There are various ways of arranging the gas jet, some of which are patented, but these do not seem to me to require special comment.

CHAPTER VI.

PATENT SYSTEMS OF VENTILATION AND HEATING—THE RUTTAN SYSTEM—FIRE-PLACES—STOVES.

THE fact that at a certain moderate depth the temperature of the earth is found to be uniform at all seasons has long been known, and a number of proposals have been made to utilize this in heating and ventilation. In his work on the British Army in India, published in 1858, Dr. Jeffreys mentions an attempt made in 1824 to ventilate with cool air a large hospital at Cawnpore, India, by means of a long and large tunnel, which, he says, failed because the cooling surface and the depth were insufficient.

In another part of the same work he proposes to ventilate the soldiers' barracks in India by making use of this principle, saying that "we may view the uppermost fifty feet of the earth's surface—or as many feet down as we can reach without the intrusion of water—as one vast equalizing reservoir, ready to absorb, from any amount of air we may choose to subject to its action, a large proportion of its summer heat, even if we do not aid our reservoir in its annual emptying itself of such heat in the cold season, but leave it to conduct back, spontaneously, such heat tardily upward to the surface during the winter months. But if we adopt proper measures for cooling thoroughly in the winter the mass of earth we select for our absorbing reservoir, we may have it emptied of more than the accumulated summer heat before the ensuing hot season, and brought down nearly to the *winter mean*, and ready, therefore, to absorb again much more heat than when it had to cool itself by the tardy spontaneous process of upward conduction through its whole mass.

"Now, if we select contiguous to a barrack of the largest size a plot of ground, *A*, *B*, *C*, *D*, Fig. 11, only a hundred yards square, or a hundred and twenty yards long by eighty yards wide—less might do—and prick it over with wells about seven yards apart, the cost of digging them all will be only £20, and we shall possess two hundred to operate upon a cubic block of earth a hundred yards square,* and say fifty

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* The plot of ground may, preferably, be oblong, as 200 yards by 50, according to the length of the barrack or barracks.

feet deep. There are numerous parts of India in which, the water being forty or fifty feet or more from the surface, dry wells to that depth may be dug; but, on the other hand, in many localities, as at Meerut, Bareilly and Delhi, the depth is much less, in some not one-half as much. In such places the number of the wells would have to be multiplied, and evaporation from the water's surface and the humid sides of the wells would make up for the effect of their inferior depth. Upon the plan proving effective it might form an important object in the choice of a station, to select localities in which the refrigerator-well ventilation could be given the best effect—whether with deep wells and a drier air, or with shallow and more humid.

"At Futtehgurh, Cawnpore, Agra, and in Bundelcund, etc., dry wells from forty to seventy feet deep may be dug.

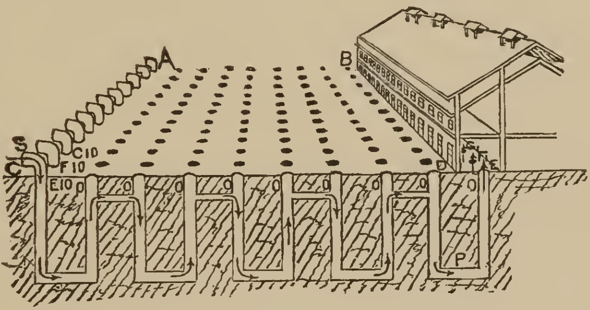

FIGURE 11.

"To put the wells in action we may proceed thus: Let *E*, *F*, *G*, etc., be successive rows of wells; the first of each row, *E* 1, *F* 1, *G* 1, being sunk in the lower veranda of the barrack throughout its length, though this is not necessary, and the mouths of this row being covered with wooden or bamboo gratings to guard against accidents.

"All the wells exterior to the building, excepting the furthermost of each row, *E* 10, *F* 10, etc., must have their mouths closed and plugged for some feet down, by straw resting on a simple bamboo frame propped across the well, as at *O*, *O*, *O*, etc.

"If the ground is wanted for exercising the men, the mouths of the wells must be arched over with brickwork and covered level with the ground around; but as this would be expensive, and the ground on one side of a barrack can generally be spared to that moderate extent, the simplest course would be to raise a common mud wall a foot or two high round each well, and to cover the straw, plugging its mouth with matting or a thin thatch. The earth dug from the wells would raise the level of the surface about a foot, and would in general yield, if the lower sand were not put uppermost, a fertile virgin soil.

"The whole area between the wells might form a productive garden, with its surface kept cool by frequent watering from a few wells reserved and deepened for the purpose, and by being covered with vegetation; but it must not be such vegetation as could be a source of malaria. This use of the surface would appreciably check the traveling of heat downward into our cubic reservoir below.

"The wells of each row must be made to communicate with each other, thus: from the bottom of *E* 1, a horizontal passage, *P*, about two and a half feet high and fifteen or eighteen inches wide, must be cut to the bottom of the next well of the row, *E* 2, and from near the top of this well below the straw about ten feet, beneath the surface of the earth, a similar horizontal passage must proceed to the next well, *E* 3, and from the bottom of this well a passage to *E* 4, and so on to the last well, *E* 10, according to the number of wells in the row.

"This last well being surmounted by a large cowl, *S* (turned to the wind by a fan-tail or a lever moved by hand), and acting as a wind-sail, the wind will blow down it and through the passage at the bottom to the next well, then up it and through its upper passage to the third well, and pursuing this course through all the wells, will make its exit through the grating of the well *E* 1, and into the veranda, *T*, which should be securely closed. As in each row of wells the last would be similarly surmounted with a cowl, every first well of each row would pour forth air into the veranda."

I have given Dr. Jeffreys' description in full, because his book is somewhat rare, and because the principle which he set forth has been made the subject of one or two comparatively recent patents, as for instance in that granted to Mr. John Wilkinson, July 29, 1879, for an improvement in tempering and purifying air and ventilating structures.

In 1876 Mr. Wilkinson published a pamphlet entitled, "How to construct a perfect dairy-room," etc., in which he gives plans for a dairy connected with a subterraneous duct about 200 feet long, through which the air supply is to be drawn, and since that time he has written a good deal for the daily press upon the merits of his patent sub-earth ventilation.

March 11, 1879, a patent was granted to Morrill A. Shepard for an improvement in producing heat and ventilation by sinking wells or shafts to reach a water-bearing stratum, in which are to be laid pipes through which the air supply for the building is to be drawn. As Mr. Shepard's object is to have his fresh-air supply pipes surrounded by water of nearly constant temperature, he would also have such pipes laid in rivers to supply adjacent cities.

The principle of sub-earth or water ventilation having been distinctly announced by Dr. Jeffreys in 1858, any one is at liberty to make use of it, but it is only under special circumstances that it possesses any practical value. In cities it would be highly inadvisable to use subterranean passages as air-supply sources, because of the great risk of contamination of the air with deleterious or offensive gases. In the country there is less risk of this, but even there the percentage of carbonic acid in the air will be markedly increased by passing it through a sub-earth duct. This, however, will not injure it for dairy supply, and dairies constructed in accordance with this principle will be found very satisfactory as regards ventilation and temperature.

The force necessary to secure a movement of air for ventilating purposes can of course be obtained by the cooling of a column of air in a shaft as certainly as by heating it, the essential point being to produce a difference in the weight of equal volumes of air by giving them different temperatures, and then utilizing this difference in weight to produce a movement of air in the direction desired.

In the great majority of cases, however, it will be found much cheaper and simpler to do this by adding than by abstracting heat.

The result of the examination of a collection of the drawings and specifications pertaining to about two hundred patents relative to the ventilation of dwelling-houses, shows that the majority of these are for forms of inlet or outlet for registers and cowls of various kinds. A few of them, however, are for systems of house ventilation involving methods of constructing the house. One inventor began by patenting certain methods of inlet and outlet, but seems gradually to have learned that these would not insure success, and he therefore devised a system and published quite a large book for the purpose of explaining it. This book, published in New York in 1862, is entitled "Ventilation and Warming of Buildings. Illustrated by fifty-four plates. * * * By the Hon. Henry Ruttan," etc.

Probably there are very few books which show a more complete and profound self-satisfaction on the part of their author than this.

He states in his introduction that he had read everything he could find on the subject—had tried experiments, and had found it all vanity. No one before himself had shown how to warm as well as ventilate a building in a cold climate by natural means and by one and the same process.

Alluding to the works of Reid and Wyman in a way to show that he had found them entirely worthless, he proceeds to lay down the following law :

"The construction of an efficient system of warming and ventilation requires that all the details pertaining to it should be reduced to one *harmonious whole*, which shall be applicable to everything. If not good in all places, it is good for nothing. It must be adaptable to the palace and the cottage, to the ship and to the railway carriage, to the habitations of animals as well as those of men, and, in addition, it must be attainable by the poor as well as the rich." The mental condition of a fairly educated man, acquainted with the general laws of heat and pneumatics, who could deliberately pen such a sentence as that, and claim that he, and he alone, had discovered such a universally applicable system as he refers to, is to me very curious and amusing. I have met with half a dozen gentlemen, each the inventor and proprietor of a patent system of ventilation and warming, who thought and talked precisely like Mr. Ruttan, each asserting that there could be but one way to heat and ventilate a house satisfactorily, and that he, and he alone, had a patent upon that method. Now, the truth is, as I have explained in previous pages, that there are many ways of effecting satisfactory heating and ventilation, the great and essential difference between them being that of expense. Some of them are specially well adapted to certain kinds of buildings, having due regard to economy, and the architect will err greatly if he undertakes to heat and ventilate his private residences, his large assembly halls and his hospital wards upon one and the same plan.

Although I cannot admit Mr. Ruttan's claim to have discovered the only perfect system of heating and ventilation, there is, nevertheless, much in his book which is true, and which is suggestive to the architect, more especially as regards private dwellings, which is the class of structures which we are now more especially considering. He says very truly: "If we want to ventilate our room to cool it, we must let the air out at or near the top, and supply its place with cool air, which, of course, will distribute itself over the floor of the apartment; and this has been the policy in nearly all our former modes of ventilation; cold air is introduced, which, taking up heat from the occupants of the room and from the fire, immediately escapes through an aperture provided for the purpose at or near the ceiling; thus proceeding on the erroneous notion that cold air only could be pure, they have actually been freezing the people when they wanted to warm them.

"If, on the other hand, we wish to ventilate our house to warm it, we must take the air out at or near the bottom, thus keeping up a continual exhaustion of the cooler air; and if we wish to set the body of air in the room in motion, upward or downward, we must, of course, bring in the necessary amount of outside air to do it. If we want to warm the room, the air we bring in must be warm, and if to cool it, it must be cool. It depends now entirely upon where you open the aperture to let the air out whether you can set this body of air so in motion or not. If you open the aperture at the top, and the air you bring in is warm—or if you open the aperture at the bottom, and the air you bring in is cold—in either case the body of air will not budge ; your warm air will go through the body, straight to and out of the top aperture ; and the cold air will do the same, through the bottom aperture. The consequence of this state of things is easily seen—you will neither warm, nor cool, nor ventilate your room.

"But if you want to ventilate your room to warm it, and open the bottom aperture, you will succeed in both ; and if you wish to ventilate your room to cool it, and open the top aperture, you will accomplish that ; because in the first case the fresh air will be the warmest and will not stop until it comes in contact with the ceiling, where, spreading out in level strata over the whole ceiling, it will keep its relative position to the whole body until it reaches the bottom and passes out of the aperture ; and so of the cold air, if you open the top and let the air out at that point. In both cases every particle of air must be removed from the room, because, as air of one temperature cannot, by any means, be made to move or stop out of its level, it follows that every *particle* of every *stratum* must in its turn leave the apartment."

Mr. Ruttan also lays great stress on the importance of keeping the feet warm, and having decided that the outlet for air must be at the bottom of the room in cold weather, and that no currents of air can be allowed on the top of the floor, he constructs his floor with an opening of two inches from the wall all around the room except at the doors and hearths, and secures free communication through the space beneath the floor by placing two-inch furring on the joists and laying his floors upon that.

The space beneath the floor thus becomes a large box containing warm foul air, and from this box suitable ducts are to be taken to the chimney flue.

It will be seen that the effect of this arrangement will be to keep the floor warm, to economize in fuel, and to make a dust-bin of the space beneath the floor.

I have been told that along our Northern frontier and in Canada, a number of private houses were built upon this plan about fifteen or twenty years ago, but I have not been able to obtain any particulars as to the results. At the commencement of his book he gives a collection of testimonials as to the success of his method, one of which relates to the heating and ventilation of a certain public hall in the city of Detroit.

In response to some inquiries on the subject, the architect of this building, Mr. Lloyd, informs me that the heating was fairly successful at first, although the temperature was too high in the galleries. Four ventilating shafts were used, one in each corner, which, as Mr. Lloyd remarks, is an error, "it being impossible to make several flues draw with equal power, and more often than not cold air will come down one or two of the shafts unless heat is employed to force the draught."

A multiplicity of outlet shafts, however, forms no part of Mr. Ruttan's system, so that it cannot be held responsible for their bad results. The method is, however, entirely inapplicable to an assembly hall, a school, or other room where a large number of persons are gathered toward the centre of the floor, and both the architect and the housekeeper will readily see numerous objections to the opening at the junction of the wall and floor. Such a house would be a paradise for vermin and a perpetual source of annoyance from loss of small articles. Any plan, however, which in a cold climate will, in the rooms of an ordinary dwelling-house, secure warm floors and the comfort connected therewith, at moderate expense and without the use of carpets, merits very careful consideration, and there is room for some good and useful work by architects in this direction.

In this country the heating and ventilation of a very large proportion of private dwellings, offices, stores, etc., depends upon some form of apparatus placed within the room itself, and not on a generalized central system of heating for the whole building. Open fire-places and grates, and stoves of various kinds, including fire-place heaters and the so-called ventilating-stoves, must always be extensively used, and it is very desirable that a series of carefully devised and properly conducted experiments and observations on various forms of grates, heaters and stoves should be made to determine the effects which they are capable of producing in connection with the question of cost.

As regards the open fire-place, we know that in moderately cool weather it is a comfortable and cheerful means of heating, but a very expensive one under most circumstances—that is, wherever the cost of fuel is more than nominal. In very cold weather the fire-place is by no means satisfactory as a source of heat, and in our Northern cities it should be considered, so far as heating is concerned, as merely supplementary to the furnace or steam heating, or even to the common air-tight stove. It wastes from seventy-five to ninety per cent. of the fuel consumed in it, so far as the work of warming the room is concerned. Considered as a means of providing an exit flue for an ordinary living room it serves an excellent purpose, and occasionally, when but a small amount of heat is desired, and that only for a few hours, as in the chilly mornings and evenings of spring and fall, the fire-place is much more convenient than the furnace. Although the great waste of heat from the ordinary fire-place is universally admitted, there have been but few careful observations made on the subject. Among the latest of these, if not actually the latest, are those reported by Mr. J. P. Putnam, in his very interesting book, "The Open Fire-Place in all Ages." Boston, 1881.

Although, as its title indicates, this work is largely historical, yet it is much more than this, for the author has not been satisfied to be merely a collector and critic of the work of others, but has undertaken to investigate for himself the action of fire-places and heaters of various kinds, and gives as the result some valuable original data, to which, it is to be hoped, that architects, furnace manufacturers and heating engineers will give special attention. The first series of experiments detailed by Mr. Putnam simply confirm the statements of Morin and Péclet as to the enormous loss of heat, and the consequent waste of fuel consumed in producing it, in the use of an ordinary fire-place. He found that in using dry pine wood only about six per cent. of the heat generated by the fuel was utilized in warming the room. In a room 29′x 20′x 10′, six and a half pounds of dry wood raised the average temperature of the room only a little over one degree F., although the heat generated was sufficient to raise the temperature of fourteen rooms of equal size from freezing to 68° F.

Another series of experiments was made with ventilating fire-places of two different patterns set in the same room in which the trials of the common fire-place were made. In the first of these, made with what is called the fire-place heater, about thirteen per cent. of the heat from the burning wood was utilized, or about twice as much as in the ordinary fire-place. The second form of apparatus tried was the Dimmick Heater, and Mr. Putnam calculates that with this eighteen per cent. of the heat produced was utilized.

The point to which I desire to call attention is not the relative value of this or that form of apparatus, for, as a matter of fact, the data given are not sufficient to determine the point with precision; but it is, that we have in this work an attempt to employ the experimental method in a scientific manner, in order to settle the question of such relative values, and that this is the only possible method by which we can obtain positive scientific data on the subject. It is not sufficient to try experiments. Every proprietor of a furnace or heater, of any kind, has done that, and is prepared to say that he has satisfied himself by experiment of the value of his apparatus. To be of value the experiments must be made and the results must be recorded in a scientific manner. Mr.

Putnam has endeavored to do this by testing the different forms of apparatus, as far as possible, under the same circumstances, placing them successively in the same room, using the same kind of fuel and for the same length of time, and then recording the results by instruments of precision—by the thermometer and the anemometer—instead of giving vague and useless opinions as to whether one was better than another.

It is true, as mentioned above, that the data are not as complete as could be wished; for example, we are not told in each case how many cubic feet of air escaped at the top of the chimney, and at what temperature, during the time of each experiment. This must be observed, and not merely calculated or inferred, in order to determine the number of heat units thus escaping, but if we could only obtain, from reliable authority, data for every form of heating apparatus similar to those given in this work, it would be a long stride toward placing the subject of heating and ventilation on a sound basis.

As this book is thus recommended, it seems desirable to point out what seems to me to be a fallacious line of reasoning in its first chapter—a fallacy which, while not materially detracting from the interest and value of the work, should nevertheless be understood by its readers. The first chapter begins as follows:

"That great radiator of heat to all living beings, the sun, furnishes those beings with the kind of heat best suited to support the life which it has developed, namely, that of direct radiation. If we would only accept this lesson, repeated every day as if for the purpose of giving it all possible emphasis, in a manner the most impressive, and with apparatus the most magnificent that nature can furnish or the mind of man imagine; if we would accept the lesson and endeavor to heat our houses after the same principles, these houses might be made as healthy as the open fields.

"We should be prompted to respect more the open fire-places as furnishing the best substitute for the life and health-giving rays of the sun, and to discard all such systems of heating as are opposed in principle to that employed by nature."

Precisely this form of argument is used to advocate vegetarianism, long hair, going naked, communism, and every other sort of "ism" and "pathy" which its advocates choose to consider in accord with what they are pleased to call "nature." The notion that in order to make our houses as healthy as the open fields, all that is necessary is to heat them by direct radiation, will simply bring a smile to the face of every educated physician or sanitarian. The author himself forgets his commencing axiom very soon, for on page 10 we find him stating that ideal perfection would imply that the supply of fresh air introduced into the house shall be warmed in winter to a temperature somewhat below that of the room, and all of his suggestions in the latter part of the book for so arranging the flues of open fires as to warm the fresh-air supply of the room relate to increasing the supply of heat by indirect and not by direct radiation.

It is, in fact, in this direction only that practical improvement in the economics of heating is to be hoped for, since it is not possible to increase the amount of heat to be obtained by direct radiation from a given amount of fuel, and at the same time secure a sufficient ventilation, beyond what the fire-places of Gauger and Rumford will effect. To secure the best effects from direct radiation a high temperature with a correspondingly rapid consumption of fuel is necessary.

To say that the heating of rooms by close stoves, or by steam or hot-water radiators placed in the room to be warmed, is heating by direct radiation, is a misuse of the phrase, for the greater part of the effect of such appliances is due not to radiant, but to convected heat—to the circulation of air heated by coming in contact with them.

All this is understood by Mr. Putnam, who says that the system of tubes which he proposes to arrange above the fire-place to heat the fresh air should properly be called a convector.

I close these remarks by quoting a passage from the book which carries its own moral. The picture of the proprietors and workmen standing around and staring with astonishment at the results of the test ought to have been given by the pencil as well as by the pen:

"Furnace makers will claim that the peculiar kind of cement they use, or their peculiar method of hammering the joints, will prevent leakage and stand fire. The writer visited a furnace advertised by the makers to be absolutely gas-tight. The joints were numerous. In some joints cast iron was connected with wrought. Pipes of cast iron were set into wrought iron plates—an arrangement the reverse of that used in the Dunklee furnace. To this the writer particularly objected, and inquired of the makers if they could warrant the furnace to stand tests at these points. The method of making these joints was, they claimed, *peculiar*.

"No cement was used, and so great was the care bestowed on each joint that leakage was a sheer impossibility. A fine, new furnace was exhibited to show the excellence of the workmanship. The writer still objected, until challenged by the makers to give proof of any of the numerous furnaces put up by the company having ever leaked gas. Without taking the time to visit any or all of the five hundred or more gentlemen whose letters of recommendation adorned the descriptive circular of the firm, the writer expressed himself satisfied if the fine, new, sample furnace then on exhibition would itself stand the test. With the assurance that he was at liberty to make any reasonable test he pleased, he ordered the furnace to be turned over and water poured into all the joints. To the complete astonishment of the proprietors and of the careful workmen standing around, the water which was poured in poured out again through nearly every one of the score of careful joints, until the furnace seemed to dissolve and float away in its own tears." (Pp. 119–20.)

In the preceding remarks upon the heating and ventilation of dwelling-houses, only such buildings have been kept in view as architects are usually called upon to plan or construct, namely, the larger and better class of city residences and suburban villas.

It has been pointed out that the problem in such houses is comparatively simple; the difficulties relating mainly rather to warming than to ventilation, although it must be confessed that, simple as it is, it has been in the majority of such houses not only unsolved, but not even supposed to exist. But what shall we say of the houses with which architects have nothing to do, but which contain the immense majority of our people, both in cities and in the country? Taking these as we find them, what should we recommend to their owners or tenants as desirable improvements?

Let us first take an extreme case, such as a room in a tenement house which is occupied by a family of four or five persons. This room, about fourteen feet square and ten feet high, must serve as a kitchen, living-room and bed-room. It is heated by a small cooking-stove, has one window, and one door opening into an interior hall, which is dark and dirty.

Every pound of fuel is a matter of importance, and every chink and cranny at which cold fresh air might enter is, as far as possible, stopped up. During cold weather, and under ordinary circumstances, it is practically impossible to do much toward improving the ventilation of this room; impossible, not because of mechanical difficulties, but because the occupants do not want ventilation, which will either make the room cold or increase the expense for fuel. Occasionally, however, in case of sickness, the doctor insists on having some fresh air for his patient, and it is well to know what can be done to secure this. Anyone who understands the general principles of ventilation and has a little mechanical ingenuity will find no difficulty in this respect. To secure a fresh-air inlet, for instance, raise the lower sash of the window from four to six inches, by placing underneath it a piece of board which will just fill the opening thus created. This makes a fresh-air inlet at the point of junction of the lower and upper sashes, and the incoming stream of air will be directed upward, so that it will not usually cause an unpleasant draught.

The same effect can be obtained by removing one of the upper panes in the upper sash and fitting to it a sort of hopper or funnel made of tin or pasteboard, so arranged as to direct the current of air to the ceiling.

The outlet must be obtained by the chimney flue, the simplest plan being to make an opening about nine inches in diameter into the flue, and so arrange a valve of paper, in a pasteboard tube or bit of stove-pipe placed in this opening, that a reverse current will be prevented, being a rough and ready application of Arnott's valve. Physicians of the poor, and those engaged in charitable work, as well as all nurses, should be prepared to devise such simple methods as these with little or no cost, and in this connection attention is invited to the essay on "An Effective and Ready Method of Ventilating Sick Rooms," etc., for which a prize was awarded by the Massachusetts Medical Society to X. Y. Z., in 1871, and which will be found in the papers of that society for 1872.

Care must be taken to make the tubes of sufficient size, for some very absurd ideas have been urged in favor of the use of small pipes. For instance, Dr. George Wyld, one of the Committee on Sanitary Science at the Society of Arts, in a paper presented to the Social Science Association in 1858, says: "I roughly estimate the diameter of the required piping necessary to ventilate any given apartment at about a multiple of the diameter of the trachea or main air passage from the lungs of those present. For instance, to ventilate a room containing generally eight individuals, a pipe about two inches in diameter would be sufficient." Upon such teaching as this, it is not to be wondered at that architects and engineers should put a low value, especially as Dr. Wyld relies on his little tube exclusively and makes no provision whatever for the entrance of fresh air.

Passing from the tenement room, let us take the small house of from three to six rooms, occupied by a single family.

Such houses in this country are usually heated by some form of stove, and have no special means of any kind for the inlet of fresh or the exit of foul air. The rooms are small, the hall, if there is one, is not heated, and the bed-rooms are warmed only on special occasions, as in case of sickness.

The house will be of brick, with 9-inch walls and plenty of cracks from shrinkage about doors and windows and at the washboards. The amount of air which would enter through these cracks, and directly through the walls of the house were it not in a block, would be nearly enough for ventilation purposes. The permeability of the walls is, however, often destroyed by papering them. To save labor as well as fuel, usually but two fires will be kept up, one in the kitchen and one in the sitting-room, and in very many houses of the kind we are speaking of, the kitchen fire is the only one to be found during the greater part of the time.

Economy in fuel and labor is here the first consideration, and to secure these results many different patterns of stoves have been devised, but with regard to the relative merits of these various patterns we have singularly little information. Mr. Brockett remarks that the efforts of the stove-makers during the last thirty years have been directed rather toward the completing of the principles of self-feeding, base-burning, hot-air feeding, and the anti-clinker arrangement, than to the discovery of any new principles. During the last ten years, however, a number of attempts to secure the introduction of fresh warm air by means of the stove have been made, and there are now on the market several patterns of ventilating stoves devised for this purpose.

When we remember that there are annually manufactured in the United States about two million stoves, representing an investment of capital of about thirty millions of dollars, the importance of this industry may be appreciated, and it is somewhat surprising that the records of experiments to show the relative merits of various forms are so scanty. So far as economy in fuel and labor is concerned, when anthracite coal is to be used, the most approved modern patterns of base-burning stoves give excellent results if connected with the proper flues, but as usually set up they not only give no aid to ventilation, but often are direct sources of contamination of the air of the room with the gaseous products of combustion. In order to secure the greatest possible utilization of all the heat produced in a stove, it is necessary that the smoke shall pass into the chimney flue at the lowest temperature consistent with securing sufficient and regular draught, and to this end much may be effected by such contrivances as sheet-iron drums, etc., which will utilize the waste heat in warming the room above. The Latrobe heater, so well known in Baltimore and vicinity, is another means of doing the same thing, and a number of similar devices, known as fire-place heaters, ventilating fire-places, etc., will be found described in the work of Mr. Putnam, above referred to.

The mode of action of a close stove has been clearly and well described by Mr. Briggs: "Surrounding any stove in active operation, there exists an envelope of air gradually ascending, as it acquires heat, toward the ceiling. In what way does this envelope come to have any considerable thickness? Air is nearly a perfect non-conductor of heat; one particle of air does not, or at least very slowly receives heat from another particle. As before stated, air permits the transmission of radiant heat without absorbing it. Only the thinnest film of air can possibly be in contact with the surface of the stove at any instant of time, and yet it is only by contact that the air is heated.

"In fact, the air does not, nor does any fluid, whether gaseous or liquid, slide upon a surface along which it passes. The movement is a rolling one. D'Arcey describes the movement of water in a pipe to be similar (but reversed) to the stripping of a glove from the finger, by turning the glove finger inside out.

"In a similar rolling movement the sheet of air passing the stove comes to have a definite thickness, and involves in its rolling process particles of air remote from the ascending stream.

"As a stone thrown into a pool transmits its vibrations over the surface, so any disturbance of a fluid body confined in an inclosure is transmitted and communicated throughout the fluid to its most distant part, with some relative intensity. There rises from the stove a current of air of considerable volume, acquiring, as it ascends, a nearly uniform temperature, but with a nucleus hotter than the general temperature of the room. This heated air endeavors to find its level next the ceiling, but to do so it must not be assumed to slide in under the warm air which it finds in contact with the ceiling. Instead of this, the interposition will be accomplished by a rolling action similar to that on the stove surface, wherein one set of particles rolls off and the other rolls upon the ceiling with mutual admixture and equalization of temperature in the process.

"With the accumulating of a stratum of heated air next the ceiling, a corresponding absorption from the floor stratum must have occurred. The necessity for the stove at all is the presumption that some loss of heat must have been going on at the windows and walls equivalent to the heat imparted by the stove.

"The windows and walls impart 'cold' in the same way and after the same laws of convection as the stove imparts heat. In one part of the room the stove will have been forming an ascending current of considerable intensity or velocity all around itself, while at another part the windows and cool walls will have a sheet of cool air, of less velocity, but of equal heat-value, traversing them downward.

"The most uniform distribution will be effected when these currents become the most general, extensive, and, consequently, most moderate. Suppose the stove to have its position remote from the windows and cooling walls, and to be so placed that the average extent of window or wall surface or exposure shall be equidistant from the stove; it can then be asserted that the column of hot air from the stove will, after rising, roll upon the ceiling and become intimately mixed and equalized in temperature with the air it finds there, and that the sheet of descending air from the windows and walls will roll out upon the floor and intermix with the air on that level, establishing an equality of temperature in that stratum. Within certain well known limits of size or shape of room, and with a close room, the lower six, or eight, or ten feet of height of the room will be heated by a stove in any weather, so that the differences of temperature within that height shall not affect the comfort of the occupant.

"Where the stove employed is so small as to demand inordinate heating of its surface to impart the required quantity of heat, successful warming is secured by protecting the occupants from direct radiation by screens of inclosing envelopes, which are found to accelerate the rising current of hot air, and this is done without very materially impairing the distribution of heat, and even when the sashes are not very tight in the window frames, tolerable uniformity of ground temperature is reached."*

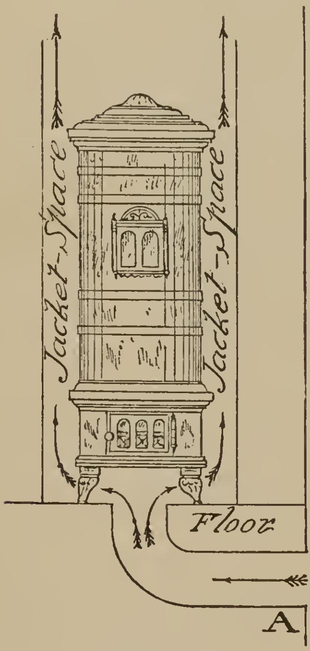

FIGURE 12.

About one-third of the effect is due to radiant heat and the rest to heat carried by the air which rolls up the heated sides of the stove and pipe. In the best forms of base-burner, with thin castings and relatively large surfaces of mica near the glowing coals, the proportion of radiant heat is greater than this, amounting to over one-half the total effect.

To arrange an ordinary cylinder or box stove so that it shall warm the fresh air entering the room, the essential thing is to surround it with a jacket of sheet iron or zinc, leaving the necessary opening for access to the stove, and then to connect through an opening in the floor the space between the jacket and the stove with the outer air. The amount of air which will be thus introduced will depend not only on the area of the opening and the difference between the temperature of the room and that of the open air, but also on the arrangement made to secure

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* The *Sanitary Engineer*, September 1, 1880, page 372.

exit of air from the room. If the room have a fire-place in it and the stovepipe enters the upper part of the flue coming from this fire-place, which is a very common arrangement, the exit of air can be readily provided for by leaving the fire-place open.

If there be no fire-place, an exit shaft may be carried up by the side of the chimney, from near the floor to near the ceiling where it enters the flue, and if this exit shaft be so arranged as to receive heat from the upper part of the stovepipe it will work very well.

Some simple methods of using the common stove for ventilating rooms are described by Dr. D. F. Lincoln in his paper on "School Hygiene," which is printed in the Second Annual Report of the Board of Health of the State of New York, for 1881–1882.

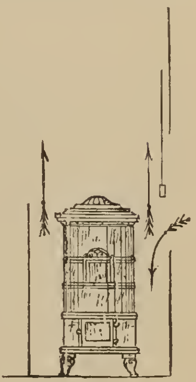

FIGURE 13.

"In a variety of ways," Dr. Lincoln says, "the stove or stovepipe can be used to expel air from the room. The 'jacket' or metal screen is a thing of which no stove in an inhabited room should be destitute, as a protection from heat. But it is mentioned here as affording an aid to ventilation. Figure 12 shows how this is done. A metal cylinder, considerably wider than the stove, is placed around the latter, and its edge is fastened to the floor. A good sized pipe is then carried through the floor, under the stove, and led through the house wall at *A*. Guard the inlet with a screen of wire at *A*, and a large supply of pure warmed air is drawn into the room. This is one of the cheapest and best devices for warming and ventilating. Some prefer to extend the jacket around only a part of the stove and leave the door uncovered; or the jacket may stop at the bottom of the stove and be made fast to the

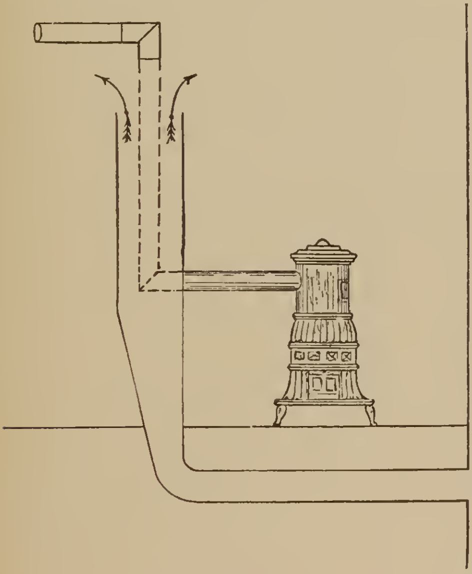

FIGURE 14.

latter at that point. The arrangement is equivalent to a 'portable furnace,' such as is usually placed in a cellar or a basement hall.

"In Figure 13 a stove is represented standing close to an open window. The movable semi-cylinder of metal, commonly used for a screen, has been so placed as to inclose the stove on all sides, except that toward the windows. Cold air may then be freely admitted ; it is quickly warmed by contact with the stove and is thrown upward with the general current.

"Figure 14 shows air brought in so as to be warmed by contact with a stovepipe. The inlet flue is enlarged and runs up with the stovepipe like a jacket, for same distance.

"Figure 15 shows how a stovepipe may assist in removing injurious air. The diagram represents a two-story house with a chimney which comes down to only a very short distance from the roof. The opening into the chimney for the stovepipe is enlarged so as to receive a much larger pipe, which encircles the stovepipe like a jacket. This jacket may stop short at *A*, or may be carried through the floor to *B*, in the first story. It will secure a draught from either story as may be arranged. The idea of this and the preceding figure is borrowed from an article in the report of the Michigan Board of Health for 1879."

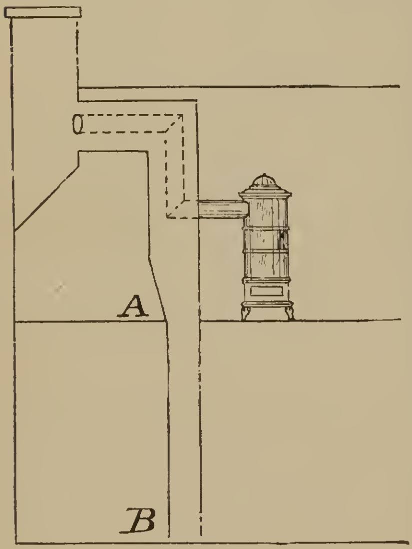

FIGURE 15.

I do not propose, however, to describe the thousand-and-one contrivances which may be used to secure the entrance and exit of air in such houses as those now under consideration. Each house is, to a certain extent, a problem by itself, but it is a very simple problem, which any moderately ingenious tinner or sheet-iron worker will have no difficulty in solving, if he will only master the few simple laws of the movement of air, which have been given in previous chapters.

Every stove-dealer should possess this knowledge in order to deal understandingly with the complaints which will be made to him about bad draught, etc., etc., complaints which are almost always due, not to the stove, but to improper construction or location of flues.

CHAPTER VII.

CHIMNEY CAPS—VENTILATORS—COWLS—SYPHONS—FORMS OF INLETS.

Within the last forty years a vast amount of ingenuity has been expended upon devices to be placed at the mouths of tubes, flues, or shafts, for the purpose of giving direction to air currents passing through them, or of enabling the wind to produce, accelerate, or prevent such currents. These devices, commonly known as ventilators, have of late been patented in endless variety, and about a dozen new ones are added to the list every year.

The outlet ventilators, which properly include all forms of chimney caps or terminals for smoke, as well as foul-air flues, were probably first planned to prevent the entrance of rain or snow into the flues, and this is still one of their most important uses. Their action depends upon two facts connected with the movement of fluids.

The first of these is what is sometimes called the law of the lateral communication of motion in fluids—the fact that a fluid in motion tends to communicate motion, in the same direction, to other portions of fluid immediately connected with it.

The second fact is the tendency of air to adhere to surfaces. When a current of air strikes a surface it is not reflected at an angle equal to the angle of incidence, as a ray of light or a billiard ball would be, but it is spread out in a thin layer upon the surface. In a valuable series of papers by F. Savart, published in the *Annales de chimie et de physique* for 1833, it is shown that "When a jet of water strikes a truncated cone perpendicularly to its axis, and just above its lower base, it spreads out, covering more than half its surface, and, rising upward, leaves its upper base in a continuous sheet, vertically, in a plane nearly coinciding in direction with that of the sides of the cone, and horizontally, nearly in the direction of tangents to the surface of the cone, while a small portion only of the fluid forms two small streams, which drop down from those two points of the lower base of the cone which are at right angles with the original direction of the jet.

"When a jet meets a plane at its centre and perpendicularly, it forms a continuous sheet over the whole surface, thin in the centre and thicker toward the circumference.

"Both the direction and continuity of this sheet are preserved far beyond the borders of the circular plane, where its edge is thin, but it follows more or less the direction of the curve of the edge, if it is thick and rounded.

"When a jet of air infringes upon a surface of limited extent, the atmospheric pressure upon the opposite side of the surface, in consequence of the lateral communication of motion, is diminished, and a current will be established through a tube, one of the extremities of which is placed in the point of diminished pressure, and the other beyond the borders of the surface. This is the important principle upon which the efficiency of ventilators and chimney tops depends; it is also important in its bearing on the position of the mouths of air-trunks for hot-air furnaces; if the mouth be placed in a point of diminished pressure, on the leeward side of a building, air may pass outward, especially from apartments on the windward side of the house."

As Dr. Wyman points out, "A simple demonstration of these propositions may be obtained by means of a card and candle. If a blast from the mouth be directed obliquely against a card, the flame of a lighted candle will be drawn toward the card, on whatever side of it the candle is held. Increasing or diminishing the velocity of the blast does not change the direction assumed by the flame, but only the velocity with which it is drawn toward the card.

"If the blast be directed perpendicularly upon the centre of the card, the flame when passed around the edge of the card will be driven outward at all points; and if the candle be held near the blast and at a little distance from the plane surface, the flame will, in virtue of the lateral communication of motion, be drawn toward the surface, and yet, by the current of air close to and parallel with the card, it will be prevented from reaching it. A strong flame may thus be made to play apparently with great force upon the hand, and yet not burn it. An illustration of this principle may often be observed in the narrow pathway, so convenient for foot-passengers, found after a snow-storm on the windward side of a high and close fence."

In accordance with these principles, it is easy to see that when a current of air flows across the open mouth of a simple cylindrical tube it must exert a certain aspirating power upon the tube, or that a small stream of air directed through a large tube tends to set in motion the entire contents of the tube, upon the principle of the well-known Giffard's injector.

The object of all cowls is to present such a surface to the wind that the sheet of moving air produced shall, on leaving the surface, be moving at such an angle to the column of air contained in the flue as to exert the strongest aspirating effect upon it. The strength of this aspirating effort varies, within certain limits, with the velocity of the current, and also with the angle which is made by the current with the axis of the flue.

Some of these cowls are made to revolve with the wind; others are fixed, and present in every direction the same form of surface and opening. As Dr. Wyman remarks, there are few objects on which so much time has been spent and misspent; and their great variety and the constant changes in their arrangement are proofs that more is expected of them than they accomplish, and that the principles on which they act are not well understood.

The effect of outlet cowls, when placed at the top of vertical shafts or flues, has been the subject of several sets of experiments.

The first of these to which I shall refer were made in 1842 by Messrs. Ewbank and Mott, and the results were reported by them in the *Journal of the Franklin Institute*, 3d series, Vol. IV., 1842, p. 104.

They directed a strong current or blast of air from bellows across the top of a glass tube, an inch and a quarter in diameter and twenty-eight inches long. The lower end of this tube was dipped into a vessel of water, and on the upper end were successively placed tin models of the various forms of cowls experimented on.

The greatest rise of the water column, showing the strongest aspiration, was obtained by the use of a short conical tube, placed at right angles to the glass tube, and having the blast directed through it from the small toward the large end.

These experiments, however, cannot be considered to be of much value, for the cross current used was stronger than a violent hurricane, and it is not safe to rely upon obtaining with full-sized flues the same results as are shown by glass-tube models in the movements of air currents.

A much more extended and valuable series of experiments upon the effect of various forms of outlet cowls was made by a committee appointed for this purpose by the American Academy of Arts and Sciences. The report of this committee, to which I have already referred, was prepared by Dr. Morrill Wyman, and will be found in Vol. I., of the *Proceedings of the Academy*, Boston, 1848, p. 307.

In these experiments a constant current of air, produced by means of a revolving fan, was used to produce an induced current in a tube, having its long axis at right angles to that of the blast; the velocity of the current thus produced being measured directly, and not by its power of sustaining a weight, or head of water, or other statical effect, which method the committee remarks is decidedly objectionable. "Such a measure gives the correct value of the initial force or tendency to establish a current in a chimney in which there is no actual movement;

but it does not indicate the velocity of the current which will be the final result of the action of the ventilator, nor is it any measure of this final velocity when ventilators of different construction are compared together. Mechanics and engineers are familiar with the differences between statical and dynamical effects of a force. In the air pump the dynamical value of any amount of exhaustion is equal to the power required to produce it, and is, therefore, proportioned to the magnitude of the receiver when other circumstances are the same ; whereas, its statical power, or its power to sustain a head of water, is wholly independent of the magnitude of the receiver, and proportioned solely to the tension of the air within it."

To measure the current, a leaden pipe 1.25 inches in diameter and 53 feet in length was placed near and a few inches below the mouth of the blowing machine. In the mouth of the trunk, attached to the blowing machine, was a tube of tinned iron of the same diameter as the pipe, and bent at a right angle ; the upright branch, about 6 inches long, reaching to the middle of the mouth, while the horizontal portion, about 5 inches in length, reached to within 2.5 inches of the end of the leaden pipe. Each ventilator, when examined and tested, was placed upon the upright portion of this tube. For this purpose the ventilator had through it, or attached to its side, a corresponding tube of the same diameter. The velocity of the blast was 10.36 feet per second, or 7.06 miles per hour. With the blast passing across the top of a perpendicular-fixed tube cut at right angles, the velocity of the induced current was 0.728 feet per second ; with a straight tube, cut off obliquely at an angle of forty-five degrees, opening turned from the blast, the velocity was 1.325 ; with a truncated cone, the velocity was 1.71 feet per second ; with a cone with cap, as laid down by De Lyle St. Martin, lieutenant in the French Navy in 1788 (see Fig. 16), the velocity was 1.56. St. Martin's cone without the cap gave a velocity of 2.21.

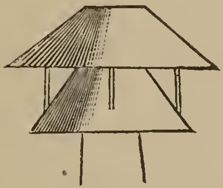

Figure 16.

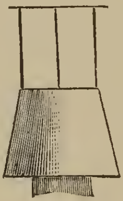

Figure 17.

The cone was proposed as a proper form for the chimney top, and an account of its application was published by Count Cisalpin about one hundred years ago. The adjoining figure (17) is an elevation from the perspective view given in the memoir. This, slightly modified (Fig. 18), is what is generally known as the Emerson ventilator, and is one of the best of all the various forms of cowls. The best form of cowl, as shown by the report of the committee just referred to, and the one which I prefer for all up-cast shafts, is shown in Figure 19. There are now no patents upon any of the cowls just described.

This matter of terminals of foul air and smoke flues occupies such a prominent, although for the most part wholly unmerited, place in the literature of ventilation, and so much stress is laid upon the merits of this or that particular form of cap or cowl, not only by patentees, but by some architects, that a few more words on the subject seem necessary.

Dr. Wyman remarks that in a strong wind any cap will be effectual which prevents the wind from beating down the chimney. "In a light, unsteady wind, the time when the cap is most needed, it is subject to a disadvantage which it is difficult to obviate. The friction is always considerable, and, under the circumstances just mentioned, the opening of the cowl will often be directed toward the wind; in this position the wind will have but little influence upon the vane, and the smoke, if the draught is feeble, will be driven into the apartment.

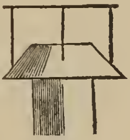
FIGURE 18.

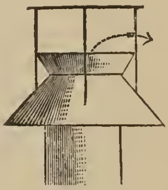
FIGURE 19.

"The steadiness of the cowl may be increased by making the vane double, the two sides forming an angle of ten or fifteen degrees (<). The single vane in common use, receiving no pressure from the wind when in its direction, has the same tendency to flap as a loosened sail. The friction may be diminished by nicer workmanship, and the noise lessened by allowing the cowl to run in leather collars; but the objection we have alluded to will only be diminished, not removed."

Dr. Wyman speaks favorably of a form of cowl which consists of a conical cap balanced on a point so that it can be tilted in any direction. The wind blowing upon it depresses the side upon which it strikes, and at the same time elevates the opposite side.

In 1878 a series of experiments were made at the Royal Observatory, Kew, England, upon ventilating exhaust cowls, by a committee composed of W. Eassie, Rogers Field and Douglas Galton, whose names are a sufficient warrant for the care with which the tests were made. The cowls thus tested were the air-pump ventilator of Boyle and the injector cowl of Mr. Lloyd, which is a fixed cowl like that used by Captain Liernur, of Amsterdam. Four upright iron tubes, each six inches in diameter and twelve feet long, were so arranged as to receive equal air supply below and the same exposure to wind above the roof of the building in which they were placed, and above which they projected about two feet. On three of these tubes the cowls above mentioned were fixed, while the fourth was left as a plain open tube, to serve as a standard of comparison. The results are given in the following report, which is a model of brevity and clearness :

"The sub-committee appointed at Leamington to test the ventilating exhaust cowls, beg to report that they have given the matter their most careful attention, and carried out at the Royal Observatory, Kew, an elaborate series of about one hundred experiments, on seven different days, at different times of the day, and under different conditions of wind and temperature. After comparing the cowls very carefully with each other, and all of them with a plain open pipe as the simplest, and in fact only available standard, the sub-committee find that none of the exhaust cowls cause a more rapid current of air than prevails in an open pipe under similar conditions but without any cowl fitted on it. The only use of the cowls, therefore, appears to be to exclude rain from the ventilating pipes ; and as this can be done equally, if not more efficiently, in other and similar ways without diminishing the rapidity of the current in the open pipe, the sub-committee are unable to recommend the grant of the medal of the Sanitary Institute of Great Britain to any of the exhaust cowls submitted to them for trial."

Of course, this report was by no means satisfactory to the inventors and proprietors of patent cowls, and in this respect it corresponds with the previous reports to which I have referred before. Each inventor obtains very different results from his own experiments, and there seems to be no immediate prospect of reconciling the discrepancies.

Mr. Hellyer, in the second edition of his work on "Plumbing, and Sanitary Houses," has an interesting chapter headed "Ventilation, or Cowl-Testing, but not at Kew," in which he gives the results of a number of experiments made with cowls of different kinds. He concludes that, while the power of a cowl to cause an up-cast of air through the pipe is not so great as some suppose, it certainly is greater than the report of the Kew Committee would lead us to believe.

He "considers that cowls should be fixed on *all* ventilating pipes for *foul air*, not so much for assisting the *up draught* as for *preventing* a *down draught*, especially where the air *blown down* through such ventilating pipes would come out near a window or door, where it should be *sucked* into the house." (The italics are in the original.)

His experiments were made with two four-inch lead pipes, each about thirty-two feet long, the tops being about six feet above the roof and four feet apart. In one of the chief systems of testing, the bottoms of these pipes were connected by a pipe in the form of the letter U, so arranged that an anemometer could be inserted and observed through a glass door. By this apparatus a cowl can be tested against another cowl or against an open pipe on what the author calls the "Pull, devil, pull, beggar, principle."

Mr. Hellyer concludes that the best cowls are better than open pipes; that the relative value of various cowls varies according to the different states of the atmosphere; that, on the whole, the best cowl is one of Mr. Buchan's, and that of Mr. Hellyer's comes second.

Many attempts have been made to combine the inlet and outlet in the same ventilator, and this either with or without connecting them with the heating apparatus. Of those combining the inlet and outlet in a single tube or shaft, which is intended or supposed to be entirely independent of the heating, the principal forms are the ventilators of Watson, Muir, M'Kinnell and Macdonald; the first three of which are described and figured in most English works in Hygiene or on Ventilation. All of these are intended to be inserted in the centre of the ceiling of the room or space to be ventilated, and the best of them is probably the double tube of M'Kinnell. "It consists of two cylinders, one encircling the other, the area of the inner tube and encircling ring being equal. The inner one is the outlet tube; it is so because the casing of the other tube maintains the temperature of the air in it; and it is also always made rather higher than the other. The outer cylinder or ring is the inlet tube; the air is taken at a lower level than the top of the outlet tube, and when it enters the room it is deflected toward and spread over the ceiling by a flange placed on the bottom of the inner tube. Both tubes can be closed by valves."

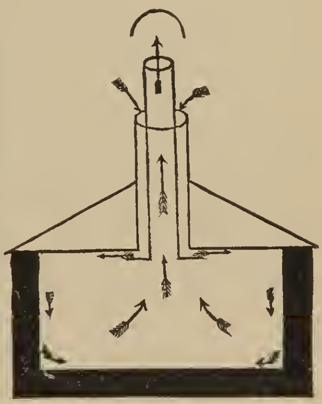

FIGURE 20.

The Macdonald ventilator is recommended in the last edition of Parkes' "Hygiene," where it is figured and described. It is similar to the M'Kinnell tubes, but has a fan within the tube which is driven by another fan placed on the top of the tube, the result being that no reversal of the current is possible so long as there is wind enough to give motion to the fan. It seems, however, rather complicated and costly, and the remarks made on page 100 upon Archimedean screw cowls apply to this also. By making the motile fan much larger, and self-regulating to secure a constant velocity, as is done in many of the modern American windmills, this principle might be made useful in some cases.

These double-tube ventilators are especially applicable to buildings containing but one room, and where doors and windows are very rarely opened, but they are useless in dwelling-houses. When a door or window is opened in the room in which they are placed, their action either ceases altogether or they become up-cast shafts—while, if there is an open fire-place in the room, they become inlets.

To illustrate the use which may be made of these tube ventilators, under exceptional circumstances, the reader may consult a paper by Dr. J. N. Radcliffe, which will be found in full in the *Sanitary Review* for 1858, vol. 4, p. 343. During the Crimean war Dr. Radcliffe had occasion to take charge of a number of sick, placed in a small shed, lit by two small windows, the sashes of which were fixed, the only opening for either ingress or egress of air being the door. This shed contained thirteen patients. It had a tiled and sloping roof, and a ceiling at a height of about ten feet. The days and nights were somewhat chilly, and any attempt to introduce fresh air from the door, windows or walls was useless. Large openings were made in the ceiling and roof, and above the opening in the roof a shaft was erected, divided by a partition and covered by a roof, large enough to prevent the intrusion of wind or rain. The result was entirely satisfactory, and there was no discomfort. Dr. Radcliffe thinks that much of this satisfactory result was due to the fact that the ventilating tubes did not communicate directly with the room, but with the attic, which formed an air-chamber, the ceiling acting as a diaphragm between this chamber and the room.

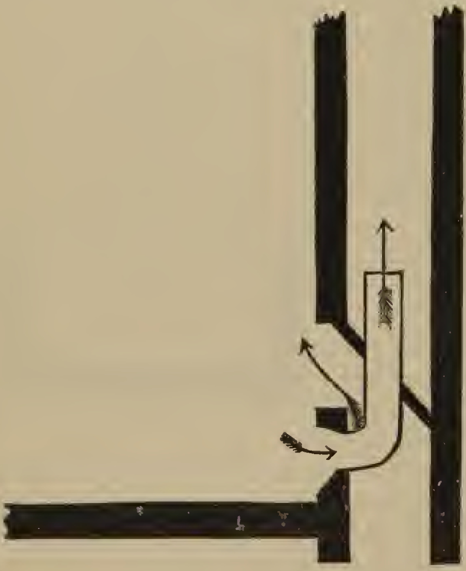

FIGURE 21.

The inlet and outlet are combined in connection with the heating apparatus in what is known as Barker's patent. In this system the hot-air and the foul-air registers are in one frame, the former being above the latter. The lower part of the foul-air flue thus passes through the upper or terminal portion of the fresh-air flue by which it is warmed.

The results obtained by this system in a ward of a hospital in Philadelphia, I have found to be not satisfactory. In cold weather a strong current is developed in the outlet flue, but the distribution of air within the room does not seem satisfactory; while with the external temperature at 50° F., the hot-air supply is in great part shut off to prevent overheating.

In the *Journal of the Franklin Institute* for 1877, p. 193, is a paper describing certain modifications in ventilators proposed by Mr. William Welsh.

One of these is a modification of the Emerson Ventilator, by the insertion of four vertical radial wings or plates. This is not patented. Another is a deflector to direct a current of heated air from the register of entrance to the floor of the room, from which it will not rise until it has traveled some distance or met with some obstruction.

This deflector has been patented, but any one can readily arrange deflecting and baffling plates or screens which will serve the same purpose, and it is well to bear in mind the good effect of doing this in all cases where there is liability to annoyance from currents of hot air.

In arranging the ventilation for a large building of several stories, the architect may choose between several different systems in planning his foul-air or up-cast shafts. Suppose, for example, that the building in question is a large school-house or a hotel, or a building containing a large number of offices.

In the first place, he may give a separate foul-air shaft to every room, which shaft shall pass directly upward to the outer air above the roof. The simplest way to do this is to give a fire-place and separate chimney flue to each room. The objections to this are the increased cost, the difficulty of arranging so many flues and chimneys in the walls and on the roof—increased danger from fire, and the risk that one flue will pull against another.

In buildings of such size and importance that it is worth while to provide some form of centralized heating for them by means of steam or hot water, the architect will usually prefer to gather the majority of the foul-air flues into a few, and, if possible, one large up-cast shaft, in connection with which he can provide means to secure a constant current, and to regulate its velocity to suit the varying requirements of the season or of the inmates of the building. This collection of the flues into a central shaft may be effected in four different ways, which are well discussed and illustrated by Planat.*

The first of these is what Planat calls aspiration from above, by which he does not mean aspiration from the upper part of each room, but from

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* P. Planat, Cours de Construction Civile, Première partie. Chauffage et Ventilation des lieux habités. Paris, 1880.

a point above all the rooms—usually in the attic—to which point all the foul-air flues are made to converge and enter a single shaft, in connection with which is a furnace or coil of steam pipe to give additional heat and ascensional force to the air.

The second method is to carry the foul-air flues of each story horizontally to the central shaft which they enter at the level of the ceiling, which may be termed aspiration on a level or horizontally. The third method is to carry all the foul-air flues downward to the cellar, where they are collected into a duct, or ducts, leading to the central up-cast shaft. This is the aspiration from below of Planat. The fourth system is a combination of the first and third, the rooms in the upper story having their flues pass upward, while the remaining floors are ventilated by flues passing downward.

In selecting from the various methods the one to be used in a particular building, the architect should be governed by the following considerations:

First.—It is desirable to reduce the number of main foul-air shafts or ventilating stacks as much as possible. One is better than two, and there are very few buildings in which more than two such shafts should be used. With one large chimney the friction is reduced to a minimum, the arrangements for control of the velocity can be simplified, and all risk of one aspirating shaft pulling against another is avoided. The question as to the employment of one or two shafts must be determined by the plan of the building and the possibility of placing the shaft in a nearly central position.

Second.—In the second, third and fourth systems above referred to, the shaft will usually be built of brick, and be of nearly uniform diameter from the bottom up. It will also in most cases be convenient to carry the smokepipe from the heating apparatus upward within this shaft. Such a shaft as this occupies more space than might at first be supposed. It will be remembered that the velocity of the air in it should not exceed six feet per second. If, then, it is to give passage to 216 cubic feet per second—which implies a building of a size to accommodate between two and three hundred persons—the chimney must have 36 square feet of clear inside area. Such a shaft will probably reach 100 feet in height, requiring thick walls at the bottom, and it will be found necessary to provide nearly 100 square feet of area for it.

In the first system above referred to, it is not necessary to carry the large central shaft up through every floor. The shaft begins in the attic, and may be made of wood, if properly lined, or of galvanized or boiler iron, according to its size.

Third.—In the first system the number of flues in the walls increases with the height; in the third system the reverse occurs. In other words, in the third system the walls are weakest below, just where they have the most weight to carry, and therefore should be thicker than when the first system is used.

Fourth.—The application of heat to the central shafts can be arranged more easily and to much better advantage in the third system than in either of the others. During the winter the heat needed for this purpose can be obtained in most cases from the smoke flue from the heating apparatus, while in summer a small furnace can easily be connected with the side of the base of the shaft. As the aspirating power of the shaft depends on the height of the heated column of air as well as on the difference between the temperature in the shaft and that of the external air, it is evident that the nearer the bottom of the shaft the extra heat is applied, the greater will be its efficacy, bearing in mind that it must be applied at a point above the entrance of all foul-air flues. In the first plan it will usually be found most convenient to apply the accelerating heat by means of a coil of pipe lining the shaft and heated by steam.

The difference in the cost of maintenance for systems one, two and three, has been computed by Planat for a building four stories high, having a ventilation of 39 cubic feet per second.

He finds that with system one it would be necessary to burn 7 pounds of coal per hour to heat the shaft ; with system two, 5½ pounds, and with system three, 4.1 pounds. The third system is therefore much the least costly of the three as regards maintenance, and it also secures greater uniformity of action and is more convenient to manage, for which reasons it should in most cases be preferred. In an old building, however, it is often much easier to apply the first system, and in some it is the only one which can be used.

When system one is employed, all foul-air flues should run in or against inside walls in order that they may lose as little heat as possible. In system three this is a matter of less importance, although in this also it is desirable to keep the foul-air flues warm. In system three it is necessary that the central shaft be kept constantly heated, summer and winter. If it be allowed to cool off in summer, there will probably be a backward draught through the foul-air flues at certain times during the day when it is cooler in the building than it is out of doors, and it will then be found very difficult to start a fire to warm the shaft. If the building is a high one and has a central hall reaching to the roof, it is necessary to take special care to make the upper part of this hall as air-tight as possible, for otherwise it may easily become a powerful ventilating shaft and antagonize the apparatus designed for ventilating purposes, besides wasting a great deal of heat.

One of the many fallacies and errors which have from time to time been urged by writers on ventilation, and with which it is desirable that the architect and sanitary engineer should be acquainted, since they are constantly coming up afresh in the form of a patent or of a letter of advice to the daily press, is that of the effect of syphons or syphon-like arrangements as exit flues for foul air, and of the effect of Archimedean screw ventilators.

A pamphlet has appeared entitled "Ventilation by Means of the Patent Pneumatic or Air-Syphon with or without Artificial Heat," which begins as follows :

"The process does not require a fire, or any other artificial heat, or moving power. It consists of the practical application of operations constantly taking effect in the atmosphere, which cause a current to take a place through an inverted syphon, having one of its branches considerably longer than the other (whether it be in the open air or with the shorter branch communicating with a room or other place), into which the air enters at the orifice of the short branch, and is discharged by that of the longer. This process is not prevented by making the short branch hotter than the long. When it is proposed, in the hereafter-described arrangements, to use the chimney as the long branch, it is because of there being such a channel at hand, and because it is capable of serving a double purpose when the season requires fire, and is conveniently available for that single purpose (ventilation) when fire is *not* required."

Upon this absurd claim it is only necessary to remark that if a syphon could of itself either create or increase a current of air, the problem of perpetual motion would be solved, and man would be able to create force.

If there is a current of air in a syphon, it is because some force is producing it, and in the great majority of cases this force is due to a difference in temperature between the bodies of air at the extremities of the tube.

With regard to the various forms of Archimedean screw ventilators, as usually made they have no effect, unless driven by power independent of the wind. In calm weather, of course, all forms of cowls are entirely inoperative, except as furnishing more or less obstruction to the free egress of air ; and on a still, warm day, when the temperature within a large building may be several degrees lower than that out of doors, there will be a tendency to a reversal of the current and to down draughts through any form of cowl that can be devised.

It often seems to be supposed by those advocating the use of this or that particular cowl, that the cowl itself has some mysterious effect in producing currents of air within it independent of wind or of differences of temperature, and that, therefore, if enough cowls are provided we can make sure of the effect desired under all circumstances. This is, of course, not the case, nor does it by any means follow that the use of two or more cowls on a building will produce more effect than one ; in fact, the effect may be just the reverse. For example, I have seen a large three-story building in which the foul-air flues from the several floors terminated in the open space of the attic, and then half a dozen patent cowl ventilators were placed in the roof to complete the arrangement. The result was that the several cowls pulled against each other, and as they were only nine inches in diameter, the result was sometimes almost inappreciable. Had a single shaft, about three feet in diameter and properly capped, been inserted, much better results would have been obtained, although this plan of using the whole attic as a foul-air reservoir is one that should be condemned under all circumstances.

With regard to inlets for fresh air, there are a number of patent contrivances designed for the purpose of preventing draughts and excluding dust, but very few of them are of any value in this country. They cannot be used in rooms heated by indirect radiation, or warmed air, as they would in most cases become outlets, and none of the patents have any special value, since it is very easy to arrange deflecting plates and filtering screens in any given case so as to produce the desired effect. It is, however, sometimes convenient to purchase ready-made valves, tubes, etc., and for this reason a few words with regard to their selection may be useful. The general principle of the majority of these patent inlets is to give such a direction to the entering current that it shall become diffused and imperceptible by the time it reaches the persons in the room, and usually this is effected by giving the current an upward direction. If the openings are to be directly in the outer walls, and not connected with the windows, the best form is the Sheringham valve, which is much used in English barracks. In this the air enters through perforated bricks or an opening covered with wire gauze or perforated zinc, and is then directed upward by a valved opening, the deflecting plate of which is so arranged that it can be set at any angle or made to close the opening entirely. (Figure 22.) The internal opening of these valves usually measures nine by three inches.

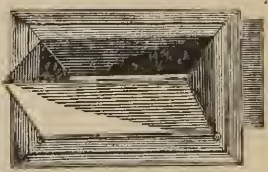

FIGURE 22.

Allusion has been made in previous chapters to the various methods of securing inlets of fresh air at the windows by separating the sashes and by contrivances analagous to the Sheringham valve. In some other cases the air may be brought in and distributed by perforated cornices, with good effect. In all cases in which the air is introduced through many small openings, it is well to have these openings trumpet-shaped, to facilitate the rapid diffusion of the current. If wire gauze, or other arrangements for filtering the air is used, it must be often cleansed or renewed.

Another form of inlet consists in what are often spoken of as Tobin's tubes. These tubes enter the room at or near the floor level, and then ascend vertically from four to six feet ; the effect being to produce a vertical current, like the jet of a fountain, to which the ceiling of a room of ordinary height will act as a deflecting plate. The principle is not a new one, and any architect or builder can use tubes of any shape or size, passing in any direction and terminating in any part of a room, for the purpose of either introducing or removing air ; and he can diaphragm or valve these tubes without hindrance from any patent. Such tubes as those proposed by Mr. Tobin work very well when the external air is above 45° F., if placed in a room having a sufficient supply of radiant heat, and an outlet-flue properly arranged.

Mr. Tobin, however, thought he had discovered that "the prevailing notions about the necessity for carefully-planned outlets were fallacious, and that if proper inlets are provided the outlets may generally be left to take care of themselves. In order to test this, he fitted two vertical tubes into a small room which had a fire-place and a three-light gas pendant. He closed the opening of the fire-place, and every other opening into the room except the tubes, hermetically, and, shutting himself within, pasted slips of paper all around the door.

"He found that there was then no entrance current by the tubes. The room had no outlet ; it was full of air, which his respiration had not had time to consume in any appreciable quantity, and no more could get in. He next lighted the three gas burners, and a steady entrance current immediately set in through the tubes and continued as long as the gas was burning. He waited nearly an hour without any deterioration of the atmosphere becoming perceptible to his senses, and with the currents steadily coming in and ascending in their customary manner. He then cut through the paper which secured the door, and left the room, shutting the door behind him. Returning half an hour later he found the atmosphere still fresh. He next extinguished the gas and the currents gradually died away, the original state of equilibrium or fullness being restored."

Upon this the *Architect* properly comments as follows : "The principles of ventilation are well known. It is the application of those principles in special cases which causes the difficulty. The amount of current of inflowing air into a room will depend upon the facilities or arrangements for outflow, and *vice versa*. Therefore, for perfect ventilation, the proportions and position of both outlet and inlet must be considered ; neither can be neglected ; and, if in the room on which Mr. Tobin experimented the air remained pure, it was because there was in addition to the inflow some means for an outflow of a sufficient quantity of air to remove the impurities given out from the lungs in breathing, and from the gas in combustion."

Captain Galton says : "The main objection to these tubes is that they form very convenient receptacles for dirt, insects, cobwebs and dust, which after a time may injuriously affect the air passing through them. Moreover, inlets of this shape do not readily lend themselves to act the part of outlets when occasion requires, which is so convenient a feature of the Sheringham ventilator."

CHAPTER VIII.

VENTILATION OF HALLS OF AUDIENCE—FIFTH AVENUE PRESBYTERIAN CHURCH—THE HOUSES OF PARLIAMENT—THE HALL OF THE HOUSE OF REPRESENTATIVES.

We come now to the subject of the heating and ventilation of large assembly rooms, or halls of audience, including churches, theatres, legislative assembly rooms, etc., etc., and to illustrate the methods which have been actually employed in some rooms of this kind in which the greatest success in obtaining fresh air appears to have been obtained.

The general principles which should govern the ventilating arrangements for such rooms are comparatively simple, and do not differ from those stated in preceding chapters. The basis of all plans and calculations is the amount of fresh air that is to be supplied. This has been discussed to some extent in Chapter III., but it seems desirable to refer to it again in this connection, in view of the fact that some of the best of modern engineers appear to be slightly skeptical and cynical as to the value of modern literature on ventilation, or as to the necessity for such quantities of air as Dr. Parkes advises, and who think "that for more than twenty years the practice of American contractors has been such as will meet every requirement of supply of air in any quantity and at any temperature desired." With regard to air supply an exponent of these views says: "The whole matter, then, resolves itself into opinions as to individual personal comfort, and to observations upon healthfulness of some of the very few rooms and places where, for a period of time more or less extended, a definite ventilation has been maintained." He then goes on to say that 30 cubic feet of air per person per minute is sufficient; that "anything may be called tolerable that is tolerated; anything may be esteemed endurable that is endured. Churches, halls, schools, theatres, state-houses, court-rooms, etc., are rendered tolerable when judicious care is taken in changing the air after a session, and in having fresh air in the audience rooms at the commencement of the same. They are endurable. Not only can little illness or actual disease be traced to them as places of origin, but, on the whole, the audiences accustomed or habituated to the closeness of the air which accompanies any lengthened session, cease to notice what would be excessively disagreeable to the newcomer entering the confined room.

People do not willingly find fault when there is apparently no remedy. Perhaps the most striking example of this salutary effect of occasional change of air, as a substitute of ventilation by constant supply, is to be found in our American railroad cars, where, in cold weather, wherein the least of regular supply is furnished to the largest number of persons temporarily crowded into the smallest space. To the outsider the heat becomes intolerable ; to the insider it is more endurable than any draught of fresh, cold air. The unhealthful condition of the car during six months of the year cannot be questioned ; and yet no serious illness that can be attributed to the want of ventilation is found among the tens of thousands of passengers ; and it is well known that the conductors, brakemen and others connected with the trains, who live in and out of the cars from day to day, are healthy beyond the healthfulness of most other men."

While there is a certain amount of truth in these statements, the whole impression conveyed by them to the average reader is certainly incorrect. I certainly do not believe that 30 cubic feet of air per minute, in rooms continuously occupied, will secure good ventilation ; nor do I think that an architect or engineer is justifiable in preparing plans upon the basis of such an amount of supply.

Under such circumstances the air will become markedly foul, and will exercise a very deleterious influence upon the health of the occupants, who will be especially liable to consumption and allied diseases if they continue to remain in it for a length of time, and who will suffer from headache, loss of appetite, want of energy, etc., from even a comparatively short exposure to such a vitiated atmosphere as this will produce. One reason why this is not distinctly recognized is because, in the computations as to the amount of air supply which is furnished to rooms, the amount which enters through cracks and crevices and through the walls and ceilings, is not taken into account, although were it not for this supply many rooms would speedily become unendurable.*

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* In this connection the following account of an experiment made by Mr. Putnam, to test the amount of air which passes through the pores and accidental fissures of an ordinary living-room, will be found of interest. The room was about five meters square and 3.6 meters high, having five windows, two doors and a fire-place, with plastered walls and ceiling and a soft pine floor.

"A flue ten meters long, from a basement furnace, furnished the rooms with hot air. The windows and doors were first made as tight as possible with rubber moldings. The fire-place was then closed by drawing the damper and pasting paper over the cracks. The brick back and jambs were oiled to render them impervious. All the woodwork was thoroughly oiled and shellacked. A good fire was lighted in the furnace, and the register opened into the room, all doors and windows being closed and locked, and the keyholes stopped up. The hot air entered almost as rapidly with the

The only safe rule is that laid down by Drs. Parkes and De Chaumont, namely: that when the air in a room has a perceptible musty, unpleasant odor to a person entering it from the outside, that air is unfit for respiration, and will probably, sooner or later, produce disease. I cannot but deprecate strongly any attempts to lower this standard on the plea of demanding scientific evidence as to the actual results which foul air produces, and also on the plea that air foul to a certain extent does not, in many instances, produce any perceptible results.

Precisely the same argument will apply to almost all measures which are recommended by sanitarians. In how many houses, for example, is gas from the sewers or from foul soil pipes escaping through pan closets, etc., without producing observed ill effects? And yet is that to be taken as a sufficient reason for abandoning efforts to secure ventilated soil pipes and properly arranged traps? The above argument is one that will be eagerly seized upon by those who have paid no attention to provisions for heating and ventilation for halls of audience, as an excuse for their ignorance, negligence, or parsimony, and will be perverted to uses of which the author probably did not dream in writing it.

The conclusion "that, for audience halls occupied for sessions not exceeding two or three hours' duration, Dr. Reid's value of 10 cubic feet of air per minute per person * * * is all that should be arranged for when planning such halls; all that can be judiciously urged in the accomplishment of ventilation, in view of the cost of fuel and apparatus;

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doors closed as when they stood open, and it continued to enter at the rate of 2.5 cubic meters per minute without diminution as long as the experiment was continued. The thermometer stood at 2° C. outside. The entering hot air ranged from 40° to 55° C. The day was March 3, 1880. Other experiments gave the same results. The pressure of the hot air from the register was sufficient only to raise a single piece of cardboard from the register. A portion of the air must have passed through the pores of the materials, and the rest through cracks and fissures which escaped detection. On the 5th of March a coat of oil paint was applied to the walls and ceilings. This diminished the escape of air only about five per cent. On the 19th of March four coats of oil paint had been put on the walls and ceilings, and three coats on the floor, to render them absolutely impervious to air. The escape of air was diminished only about ten per cent. On the 25th of March all the window sashes were carefully examined, and all visible cracks at the joints, at the pulleys, cord fastenings, etc., carefully calked and puttied, and the entire room examined, and putty used freely wherever even a suspicion of a crack could be found. The result of all this was a diminution at the utmost of but twenty per cent. in the escape of the air, or, in other words, in the entrance of air through the register. Each experiment was continued during more than an hour. The air entered as freely at the end as at the beginning of the hour, when a volume of air more than equal to the entire capacity of the room had entered it through the register, with no visible outlet." J. Pickering Putnam. *The Open Fire-Place in All Ages.* Boston, 1881, p. 137.

quite sufficient to meet the physiological issue, and so large that it ought to be accepted from the medical point of view," is one that I must most positively deny. The amount of supply for such halls should in no case be less than 30 cubic feet of air per minute through the regular flues of supply, and in legislative buildings the apparatus should be such that at least 45 cubic feet of air per person per minute can be furnished, with a possibility of increasing it to 60 feet per minute when desired. In dealing with such matters as air and water supply, engineers should endeavor to secure maximum and not minimum quantities.

I am quite sure that no architect or engineer would advise making plans to correspond with the requirement of 10 cubic feet per minute per person, if the question of expense of construction and maintenance did not come in ; and the difference between the opposing views is in the main that one considers the question of cost as more important than others are disposed to do. So far as construction is concerned, the difference in cost between providing for an air supply of ten and one of sixty cubic feet per minute will not often be so great as to be a serious objection, *provided the plans be made before the construction of the building is commenced.*

It is when we have to provide heating and ventilating arrangements for existing buildings which have been planned in utter ignorance of the requirements of heating and ventilation—and this is the case with at least one-half of the largest and most costly buildings in New York—that we have to diminish the supply of fresh air to the smallest permissible amount in order to be allowed to introduce any at all. The ventilation of such buildings cannot be made satisfactory ; it is only "endurable," and a ventilation which is only just "endurable" is discreditable to the architect of the building in which it occurs, provided that his advice has been followed on this point.

Halls of audience or assembly may be roughly divided into three classes. The first are those which are to be occupied not more than three hours continuously, and which do not have clear stories below them devoted to other purposes. This includes the great majority of churches and theatres. The second class include those which may be occupied for many hours continuously, such as legislative assembly halls. In these, expense, whether for construction or maintenance, is usually a very secondary matter, and the blame for insufficient ventilation rightly falls on the architect. The third class includes lecture-rooms, etc., which are placed in the second or third stories, the rooms below being occupied, and not available for ventilating purposes.

A good illustration of a building of the first class is the Fifth Avenue Presbyterian Church of New York City, commonly known as Dr. Hall's

Church. I select this because it has been specially commended for its ventilation by competent judges, and, among others, by Captain Galton, who speaks of it as the best ventilated church he has seen.

I am indebted to the architect, Mr. Carl Pfeiffer, of New York, for the data and drawings used in the following description :

This church covers an area of 100 by 200 feet, and the auditorium is 100 feet deep on the main floor, 136 feet deep on the gallery, 85 feet wide, with a ceiling 60 feet high, and is intended to furnish comfortable seats for 2,000 persons. At the northwest corner of the building is a tower 100 feet high and 16 feet square, which serves as a fresh-air shaft, down which the air is drawn by a fan at the base of the tower. The entire basement of the church is a fresh-air chamber, on the ceiling of which is a network of steam-heating pipes, two inches in diameter, amounting altogether to 9,000 feet in length. There is also an auxiliary coil in the air chamber adjoining the fan, containing 4,410 feet of 1-inch pipe, which is divided into four separate steam coils, each of which can be used independently. This auxiliary coil is in itself nearly, or quite, sufficient to furnish all the heat required under ordinary circumstances. But the pipes beneath the floor have been found very useful in warming the floor of the pews. The basement extends under the entire building, and is about nine feet in height. It is not ceiled or plastered. The warm air forced by the fan into this basement air chamber, passes into the body of the church through openings in the risers of the stationary foot-benches of every pew, these openings being controlled by slats, or registers, in such a way that the occupant of each pew can regulate the inflow of air at his pleasure. The air also escapes into the aisles through openings in the ends of the pews.

Steam is usually turned into the pipes underneath the floor about twenty-four hours before the service in winter, and is turned off when the audience begins to enter, when the fan is put in motion. The forcing in of fresh air by the fan is continued between the interval of the morning and afternoon services, thus thoroughly flushing out the church. In warm weather the air is cooled by the spray of water from a perforated pipe at the bottom of the fresh-air shaft, and by the use of ice the temperature of the incoming air has been lowered as much as six degrees.

The fan is similar to that used in the Capitol at Washington, is 7 feet in diameter of disk, 8.5 inches wide at the tips of the blades, 5 feet in diameter at the mouth, 15 inches width of blades at the mouth, having 3/8 of an inch clearance between the edges of the blades and the wall or fan side, with an area of 19 square feet at the mouth and 15 square feet at the periphery. The area of the duct or passage leading from the chamber is 20¼ square feet.

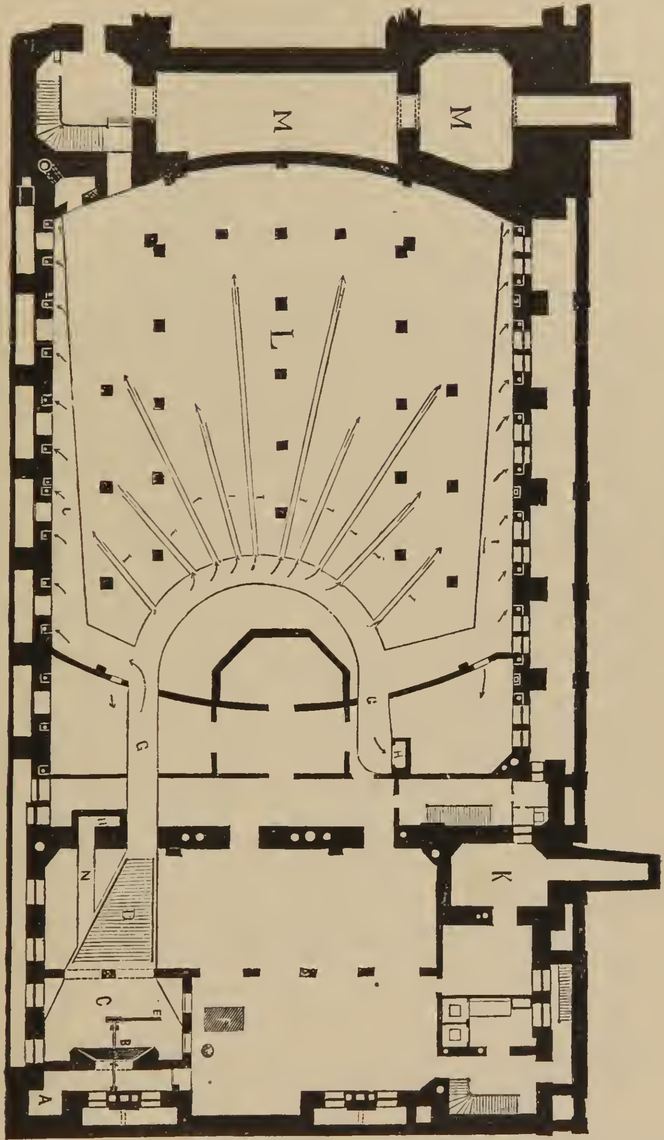


FIGURE 23.—PLAN OF BASEMENT OF FIFTH AVENUE PRESBYTERIAN CHURCH, NEW YORK CITY.—CARL PFEIFFER, ARCHITECT.

A.—Fresh-air supply shaft from tower. Entrance for air 75 feet above ground.
B.—Fan.
C.—Air chamber.
D.—Heating coil. 4,410 feet of 1-in. pipe.
E.—Belt.
F.—Engine.
G.—Air duct.
L.—Air chamber for auditorium.
M.—Coal.

The results of some experiments made upon the operation of this fan by Messrs. Skeel and Nason will be found in the *Journal of the Franklin Institute* for August, 1876, page 97. With a velocity of 66 revolutions of the fan per minute, the velocity of air in the delivery

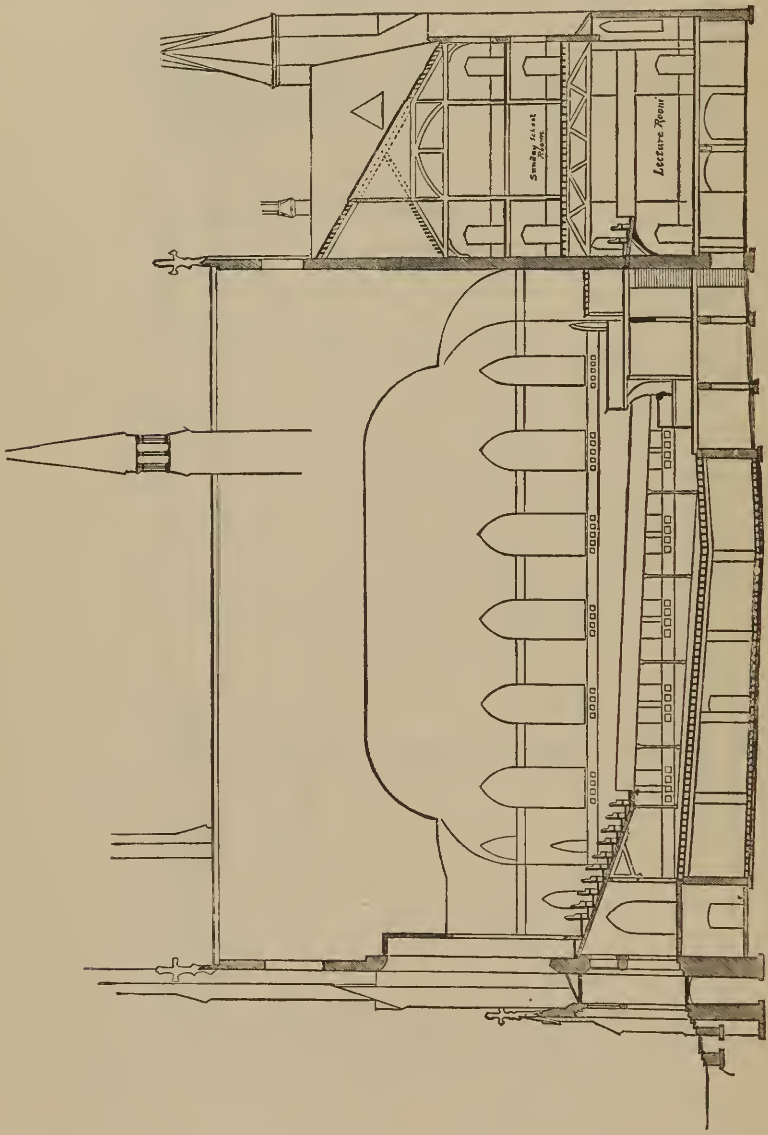


FIGURE 24.—LONGITUDINAL VIEW—FIFTH AVENUE PRESBYTERIAN CHURCH.

duct was found to be 484 feet per minute, amounting to 9,900 cubic feet per minute. With the fan running at 110 revolutions per minute, the number of cubic feet delivered was 15,370. The authors make the following comment. Referring to experiment No. 1, when 9,900 cubic feet of air was supplied, they state that "at the end of the service of one and a half hours, with 1,400 people in the church, the proportion of carbonic acid in the air was found to be 12½ to 10,000."

An experiment made on the 4th of June, 1876, with the external temperature at 84°, showed that with the delivery of 631,000 cubic feet of air, being 465 cubic feet of air per man per hour, the speed of the air through the registers was, near the centre of the church, from 80 to 135 feet per minute. The temperature of the air in the air shaft was 77. When the water spray was turned on the temperature of the air entering the church was 73, the temperature of the water itself being 69.

Complaints have been made at times by some of the audience of unpleasant draughts, and to prevent these there is a tendency to close the registers in the pews. When this is done in a part of the pews, the effect is to increase the velocity of the current through the remaining openings, and thus to induce the closure of these by those exposed to such currents. It is therefore impossible, when the church is full, to supply the amount of fresh air requisite to keep the proportion of carbonic acid down to 8 parts in 10,000, which is, I think, a fair standard for a building of this kind. To effect this, it would be requisite to increase the area of fresh-air openings in the floor, and probably a good way of doing this, without producing unpleasant draughts about the feet and ankles of the occupants, would be to have the partitions between the pews made hollow and used as air ducts, delivering the fresh air directly upward. This would increase the amount of air supply, and at the same time diminish the velocity of the currents through the lower openings to such an extent as to remove the desire to close them on the part of the pew-holders.

As it is, however, this church is a vast improvement on the great majority of such structures, in which, as a rule, there are no special arrangements for the distribution of fresh air through the audience, and the effects of the steady increase of impurity in the air are usually distinctly perceptible in the audience during the last half hour of the service.

Probably no legislative hall of assembly has been the subject of more complaints, or of more experimental changes, than those of the Houses of Parliament in London, and I therefore give, nearly in full, a careful description of the outcome of all these experiments, which description was prepared in 1876, under the direction of Dr. John Percy, F. R. S., by J. H. E. Walters, E. M., for the information of a commission engaged in investigating the ventilation of the House of Representatives in Washington, to which reference is made hereafter.

The present system of ventilation in the Houses of Parliament is a modification by Dr. Reid, Sir G. Gurney, and Dr. Percy, of the system adopted by the committee of 1840, appointed to inquire into the causes of the frequent complaints from members of bad ventilation and defective communication of sound. To carry out the purpose the whole of the spaces beneath the floors of both houses (Lords and Commons), and above the ceilings, were planned and prepared by the architect, Sir C. Barry.

The problem was the adequate renewal of the air in such a manner as not to prove disagreeable or injurious to the assembled members. It was, however, some years before a satisfactory arrangement of the system was arrived at, and even now complaints are occasionally heard which, though in rare cases they may be well founded, result, it is certain, more generally from special constitutional conditions of individuals.

The difficulty of affording general satisfaction is increased by the fact that the same external temperature does not equally affect the same individuals at all times, without considering the great diversity of temperament that must necessarily exist in a large assembly.

An estimation of the supply of fresh air needed, in order to prevent the amount of carbonic acid present from exceeding its usual limit (= .0008–.0005 by volume), is easily made, but this proves nothing with regard to the volume of air required to remove the organic matter and watery vapor given off from the surface of the body. It is upon the assumption by some people that this matter is heavier than air that systems of "downward" ventilation have been held preferable, but this has not been confirmed by the results obtained. There is one fact which admits of no doubt, viz.: that, provided the temperature and moisture be suitable, the amount of air admitted (without draughts) cannot be too great. Dr. Parkes, in his work on Practical Hygiene, observes: "Wherever practical, we should be content with nothing short of an unlimited supply."

The velocity desirable in the air-current varies with the temperature. In hot weather, air, even at 75°, may be made pleasant to the feelings by increasing the velocity. The exact ratio, however, between velocity and temperature is difficult to determine.

Experience has shown that, in warming a large chamber, the chief point is that the *whole of the air supply shall be admitted at the temperature required, and not* (as is usually done) *by warming the larger volume of cold by admitting to it a smaller quantity of hotter air.*

In proportion to the number of openings by which a given amount of air is supplied to a chamber, can the velocity be increased without draughts.

The amount of moisture present is a point of very great importance. In hot weather, if the air be heavily charged with moisture, a sensation of languor and lassitude is induced ; on the other hand, when an insufficient quantity of water is present, a sensation of dryness in the throat and bronchial irritation is experienced, as during the prevalence of the dry east winds of this country.

The commission appointed by the House of Commons in 1856 stated that it was absolutely necessary that water be present in the air to the amount of a little less than three grains per cubic foot with a temperature of 50° ; nearly four grains per cubic foot with a temperature of 60° ; and to more than five grains per cubic foot with a temperature of 70°. An excess of this amount has the important effect stated above.

Much controversy has taken place on the merits and demerits of ventilation by mechanical propulsion of the air and by exhaustion by heat. The latter is now generally considered to be the better plan, wherever practicable, and it has been adopted in the Houses of Parliament exclusively (except during the hottest weather, when efficient ventilation by the furnaces is difficult).

The principle is identical with that employed so largely in collieries, viz.: the heating of the column of air in a shaft placed in communication with the exhaust-air channels and flues.

The advantages of the system are, absence of machinery and mechanical appliances, so that no skilled labor is required, and, if judiciously and well arranged, it is not affected by external gusts and currents of air, and also that by availing ourselves of natural forces at our command, expenditure is proportionately lessened.

A noticeable and important defect in most systems of mechanical ventilation is the pulsatory movement induced in the air current, and the noise consequent on the least neglect on the part of the machine attendant.

In the case of a large assembly, as in the Houses of Parliament, whatever system of ventilation be employed, it is only by constant supervision on the part of the attendants of atmospheric changes and the varying number of members present that an equable temperature, with good ventilation, can be maintained, and the demands of the assembly satisfied.

The improvements adopted consisted in the addition of chambers immediately below the floors of the houses and above those in which the heating apparatus are placed, with the view of preventing local currents and eddies, and the possibility of a *perceptible* movement in the air in any one part. General diffusion of the fresh air being the desideratum, the floors of the houses are formed of cast-iron gratings, which are overlaid (in the House of Lords) with hair carpet and with coarse hemp netting (in the House of Commons). These gratings, forming the ceilings of the equalizing chambers, allow of the free admission of a large quantity of air with a perfect absence of draught.

Below the equalizing chambers, and communicating with them by *grated* openings, is another chamber, containing the heating arrangement or other apparatus for such treatment of the air as the state of the atmosphere may necessitate. The whole of the space occupied by the heaters is surrounded by a gauze screen, which acts as a filter to arrest any coarse particles of dust, etc., that would otherwise pass into the house. In summer the air is more or less freed from dust, by passing through fine water spray.

The velocity (*i. e.*, the quantity) of the air passing is regulated by a sliding door or valve, placed in the foul-air exit, above the ceiling of the house. This is actuated by hydraulic arrangement, and is under the control of the attendant stationed in the air chamber under the house.

The panels of the ceilings are raised, leaving spaces around their edges, through which the foul air from the houses is drawn off up to the up-cast shafts.

In the Commons each set of gas-burners is connected by a vertical tube with a main flue (running the length of the ceiling), in connection with the up-cast shaft, into which the products of combustion pass.

The position of the air-supply channels is a point for careful consideration. It was formerly considered that by drawing the air from the top of one of the towers a purer supply would be obtained than if taken from the ground level. This has (in London), however, proved to be a fallacy; the air thus obtained was the most contaminated with smoke and other impurities.

In the House of Commons the air-inlets are placed in the "star" and "commons" courts, and are of limited area as compared with those of the House of Lords, thus making it more difficult to insure uniformity of the air-current in its passage upward. Special attention is given to the cleanliness of these courts, especially during hot weather. The surface is laid in asphalt and is sluiced with water several times daily, and any horse manure, etc., immediately removed. During the hottest weather the air has been cooled by passing it over blocks of ice placed on wooden racks in the air-ways.

The surface of the ice exposed, however, being small in proportion to the volume of air passing, the temperature was but slightly reduced, usually not more than one degree (1°), yet the air thus treated, it was thought, produced a sensation of freshness, which possibly might be due to the condensation by the ice of the excess of moisture present. This was particularly noticed on one occasion, when the temperature of the air was nearly the same before and after passing the ice.

The accompanying table of extracts from the official journal of 1875 shows the equable temperature maintained in both houses through a considerable range externally :

TABLE OF TEMPERATURES IN THE HOUSE OF COMMONS.

Date.	Time.	Speaker's chair.	Members' gallery.	Bar.	Retiring rooms.	Division lobbies.	Commons' lobby.	Out of Doors.	Dew-point.
		°	°	°	°	°	°	°	°
February 9, 1875....	10.00 a.m.	61	61	60	61	57	57	33	61–53
	5.00 p.m.	61	61	61	65	63–64	59	35	......
	10.00 p.m.	64	66	64	68	65–66	62	36	60–52
February 12, 1875...	10.00 a.m.	62	62	62	62	58	58	44	61–53
	5.00 p.m.	62	63	62	63	62	63	45	......
	7.00 p.m.	64	65	64	63	65	64	46	......
March 2, 1875......	10.00 a.m.	59	58	58	54	54	54	33	61–52
	5.00 p.m.	61	60	62	61	60	61	36	......
	11.50 p.m.	65	64	65	61	63	65	36	61–53
April 5, 1875.......	10.00 a.m.	58	58	58	56	56	56	50	......
	5.00 p.m.	61	62	62	63	59–61	58	53	62–53
	11.00 p.m.	63	65	63	63	62–63	61	46	......
May 3, 1875........	10.00 a.m.	61	61	61	62	59	62	62	......
	5.00 p.m.	62	63	62	62	62–63	63	63	63–58
	11.50 p.m.	62	66	64	65	63–64	64	57	......
June 1, 1875.......	10.00 a.m.	63	64	63	65	65	63	64	65–59
	5.00 p.m.	66	66	66	66	64–66	66	68	......
	11.50 p.m.	64	67	65	68	64–66	65	58	......
July 6, 1875........	10.00 a.m.	66	66	66	66	66	66	65	65–52
	5.00 p.m.	68	69	68	70	68	67	72	......
	10.00 p.m.	68	70	69	70	68	68	66	......
August 14, 1876....	10.00 a.m.	71	72	71	74	71	74	76	70–65
	5.00 p.m.	73	74	74	76	73	75	81	......

TABLE OF TEMPERATURES IN THE HOUSE OF LORDS.

Date.	Time.	Lobby.	Bar.	Table.	Throne.	Princes' chamber.	East corridor.	West corridor.	New corridor.	Out of doors.
		°	°	°	°	°	°	°	°	°
February 9, 1875..........	10.00 a.m.	58	60	60	60	58	56	55	52	33
	2.00 p.m.	60	63	....	63	61	60	56	54	33
	6.00 p.m.	61	64	62	64	64	64	58	57	....
February 12, 1875..........	10.00 a.m.	60	62	62	62	60	61	58	56	44
	2.00 p.m.	60	63	....	63	63	63	60	58	....
	7.00 p.m.	62	64	64	65	65	63	62	61	....
March 2, 1875..............	10.00 a.m.	58	60	60	60	57	58	56	54	33
	2.00 p.m.	60	61	....	62	62	60	58	56	....
	6.00 p.m.	61	63	....	64	65	63	60	58	....
May 3, 1875..............	10.00 a.m.	60	62	62	62	62	62	60	60	62
	2.00 p.m.	61	64	....	63	63	62	61	62	....
	6.00 p.m.	62	64	64	63	62	62	62	62	....
June 1, 1875..............	10.00 a.m.	60	62	62	62	61	63	60	59	64
	2.00 p.m.	61	64	....	63	63	62	62	60	....
	6.30 p.m.	62	65	....	65	62	62	62	61	....
July 6, 1875..............	10.00 a.m.	64	65	65	65	65	65	64	63	65
	2.00 p.m.	65	67	....	67	66	65	64	64	....
	7.30 p.m.	66	68	....	67	67	66	66	65	....

The fresh air is admitted by the louvre openings, *A A* (from the court-yards on both sides of the house), to the warming chamber, on the floor of which the heating batteries, *B B*, are arranged in four equidistant and parallel rows. These are surrounded by a gauze filtering screen, as indicated by the dotted line. The spray jets used in summer for cooling and purifying the air are placed in the arcades outside immediately in front of each set of louvres. The heated (or cooled) air ascends through gratings, *C C*, in the openings to the equalizing chamber, *D*, from whence it is distributed to the house (through the grated floor) and to the galleries (by the openings and flues, *E E*).

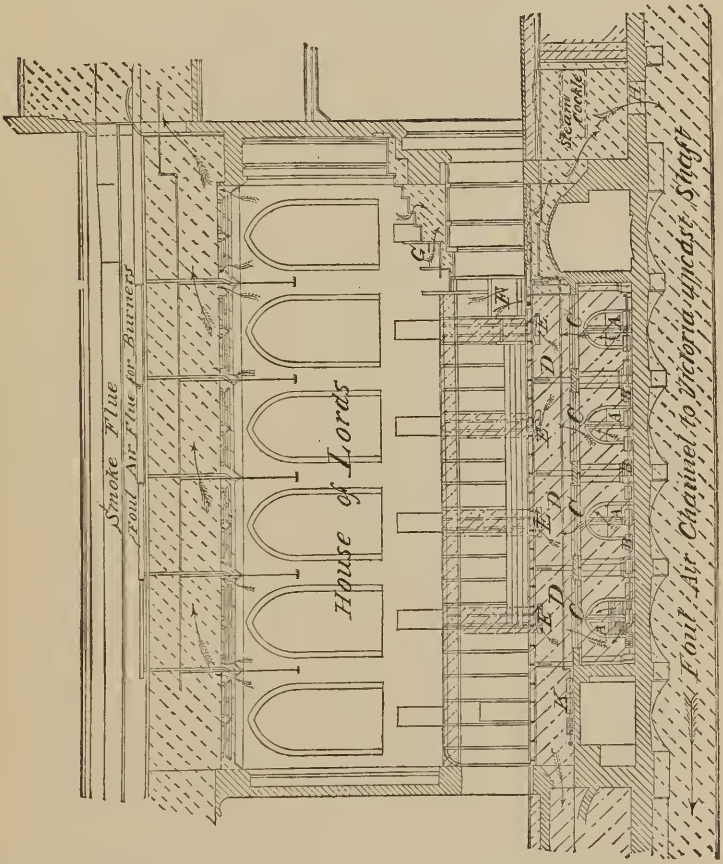


FIGURE 25.—SECTIONAL ELEVATION OF THE HOUSE OF LORDS, SHOWING WARMING AND VENTILATING ARRANGEMENTS.

The vitiated air is drawn off through the openwork in the ceiling to the foul-air space, in communication with the up-cast shafts, and also

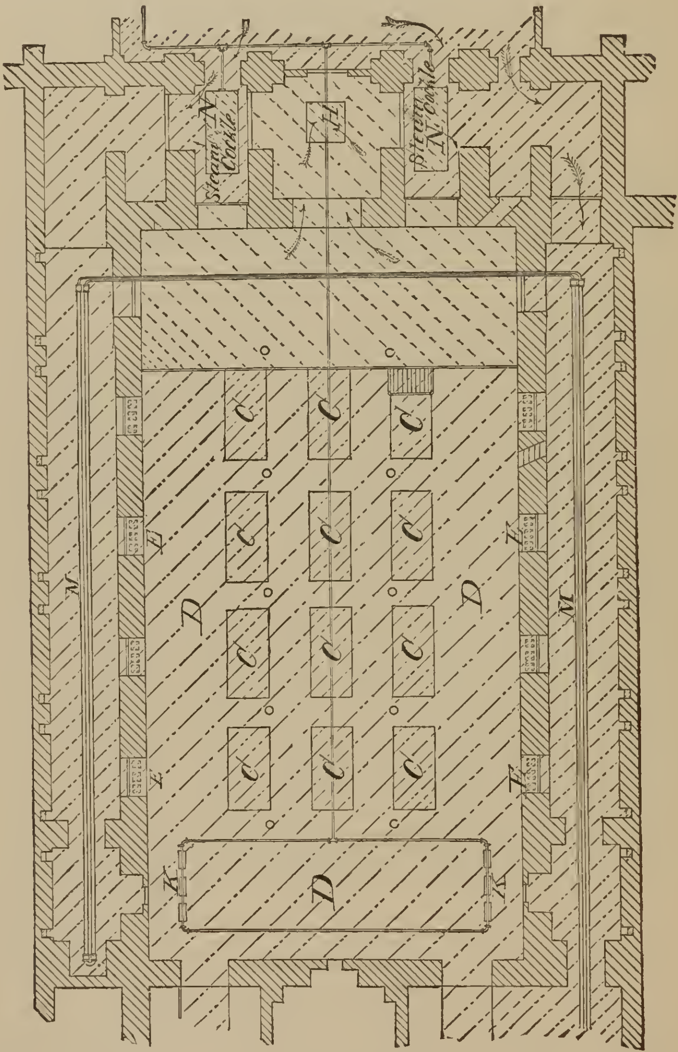


FIGURE 26.—HORIZONTAL SECTION THROUGH EQUALIZING CHAMBER OF HOUSE OF LORDS.

through openings behind the bar, *F*, to the Victoria tower by the down-pull, *H*, as clearly shown on the drawing.

Figure 26 shows a horizontal section through the equalizing chamber of the House of Lords. The lettering is the same as on Figure 25.

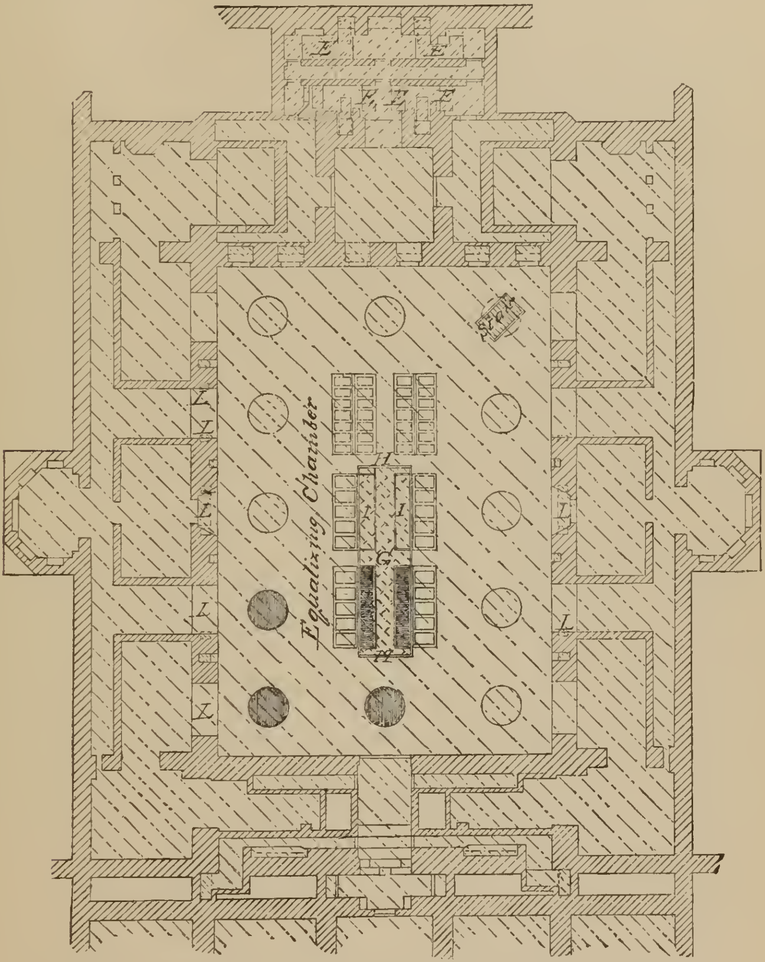


FIGURE 27.—HORIZONTAL SECTION THROUGH HOUSE OF COMMONS.

The batteries, *K*, are for heating that part of the house immediately beneath the throne; *M* are steam pipes for heating the air supply to the division lobbies. The "steam cockles," *N*, formerly constituted the chief means of heating the air supply to the House of Lords, but they are now rarely used, and are, moreover, difficult to clean and keep in repair.

In the House of Commons, during the hottest weather, a difficulty was experienced in passing a sufficient quantity of air by means of the furnaces (or only by keeping up inordinately large fires therein). This is in part due, doubtless, to the limited number and area of the air inlets, and the extent of the channels the air is required to pass before and after supplying the house.

To remedy this defect, an air machine was placed in the lower chamber to act instead of, or to assist, the furnaces.

The machine is double-acting. The blowing chambers are rectangular in section (8′x 6′6″) and are placed side by side, the two occupying the width of the vault in which they are placed. The pistons are supported on double piston rods running through stuffing boxes at both ends.

The machine is driven by noiseless friction gearing from a small vertical engine of four horse power, and is capable, at sixteen strokes per minute, of renewing the air in the house in nine minutes ; or, in round numbers, six times every hour. The valves are of simple construction, of thin sheet India rubber, bending on wire seatings.

The boilers are of the type known as "Lancashire," 25 feet long and 7 feet diameter, double flues, 2 feet 9 inches throughout.

In winter, three of these are kept going to supply the heating and other apparatus throughout the building.

The next illustration of methods of heating and ventilating large legislative assembly halls to which I wish to call attention, is to be found in the arrangements for the hall of the House of Representatives of the Capitol at Washington. It is well known to all who have given attention to the matter that these arrangements have been the subject of many complaints and of several investigations, almost as many, in fact, as the more famous ventilation of the Houses of Parliament in London. The first of the Congressional documents relating to this subject, which has now any interest or value, is what is commonly called the Wetherell Report, being Executive Document 100 of the House of Representatives of the first session of the 39th Congress, dated May, 1866.

This document contains brief reports by Mr. Walter, the architect, and by Professor Joseph Henry, of the Smithsonian Institution, transmitting a long report by Dr. Charles Wetherell, giving the results of experiments and tests made by him to determine the proportions of carbonic acid present in the hall under various circumstances.

These results showed that the amount of carbonic acid present was relatively very small, and that the gas was very uniformly diffused throughout the hall.

The report gives an extensive and valuable series of tables comparing these results with those obtained by other investigators in lecture-rooms and theatres in Europe. The paragraph, "on the direction the products of respiration take after leaving the body," is worth reproducing, and is as follows:

"Mr. Goldsworth Gurney, in his testimony before a committee of the House of Commons, asserts that the breath is forced downward through the nostrils *to the ground*, which is the natural provision against breathing the same air over again. He proves the fact by tracing the downward course of the current by the condensation of the breath of the nostrils on a frosty day. This opinion is quoted by those authors who approve of the downward system of ventilation and it is given also in an admirable treatise upon the elements of ventilation, contained in a report by Messrs. Shedd and Edson to a committee of the Massachusetts Legislature.

"The conditions are different for a person in the external air and when in a room raised to a comfortable temperature. In the former case the breath, nearly saturated with moisture from the temperature of the body, parts with a large portion of its water by the action of the hygrometric condition of the cold external air. These particles of water thus produced are specifically heavier than air, and their tendency to fall is assisted by the downward impulse from the nostrils. The experiment, to be fair, should be performed in the room, and at the temperature concerning which the practical conclusions are drawn. On March 27, 1865, at 1.30 P. M., in the laboratory of the Smithsonian Institution, the temperature of which was 69.26° F., a delicate thermometer, held in the hand for several minutes, indicated 95.36° F. Held in the mouth, and observing the degree by the aid of a mirror, it indicated the same temperature. Upon smoking a pipe with a stem of wood six inches long, slowly, with the thermometer also in the mouth, the temperature did not sensibly rise. Having thus obviated a source of error from any supposed heat in the tobacco smoke, I experimented upon the air currents of the breath, both while sitting and standing, following them readily by aid of the smoke.

"Before expulsion the smoke was held in the mouth for a short time to insure its temperature to be the same as that of the breath, and the hot pipe was held or placed aside. When the smoke is expelled gently from the nostrils, as in the act of breathing, it proceeds downward for a foot or less, and then rises rapidly. It rises more rapidly when in the sitting posture, by reason of the current of warm air ascending from the legs.

"When the smoke is blown with great force through a glass tube, it can be made to reach the ground, but the tendency after it loses its momentum is still upward. Blown horizontally, it rises as soon as the horizontal force is exhausted, which depends upon the force of the blast. The smoke blown upward through the glass tube rises very rapidly, as may be seen also by the rings of smoke which some persons delight to produce." (Pp. 69–70.)

Dr. Wetherell concluded that "the principal defect of the air," and the cause of complaint, is in the hydration, and in this opinion Professor Henry concurred.

Very little was done after the presentation of this report, and it was not until 1876 that the matter was taken up in earnest. A board was then organized, consisting of Professor Henry, of the Smithsonian Institution; Col. Carey, of the U. S. Engineers; Mr. Clark, the architect in charge; Mr. Schumann, C. E., and Dr. Billings, U. S. Army, whose report was presented in January, 1878, and forms Report No. 119 of the Documents of the House of Representatives of the second session of the 45th Congress.

As this document is not readily accessible to the majority of readers, and as it treats of some of the difficulties in arranging the ventilation of assembly halls of this kind, the following extracts are given:

"The standard of purity of air in an audience hall, which is recommended by the board, is that fixed by the late Dr. Parkes, viz., that the ratio of carbonic acid (which is selected simply because it can be conveniently measured) shall not exceed 6 parts in 10,000, and to secure this it has been shown that about 50 cubic feet of fresh air per man per minute must be introduced and thoroughly distributed.

"The problem of ventilation of the Hall might therefore be stated as follows: How to introduce and distribute from 30,000 to 60,000 cubic feet of fresh air per minute—corresponding to from 600 to 1,200 occupants—and to do this in such a way that the occupants shall not be annoyed by heat, cold, or currents of air.

"Even were this done, perfect ventilation would not be obtained, for this would only provide for dilution of the impure air, while in perfect ventilation the impurities are not so diluted, but completely removed as fast as formed, so that no man can inspire any air which has shortly before been in his own lungs or in those of his neighbor.

"To secure such ventilation as this, horizontal currents must be avoided, and all the air in the room should be made to move directly upward or directly downward. It is utterly impossible to thoroughly ventilate such a hall as that of the House, if fully occupied, by any so-called natural ventilation by means of doors and windows.

"The majority of such halls now in existence are heated and ventilated by currents of air passing from below upward; but the Chamber of Deputies at Versailles is arranged for downward ventilation, and, to judge from the documents laid before the board, this method would seem to be preferred by many theorists on the subject. * * *

"The relative merits of the upward *versus* the downward systems of ventilation in large halls in which the centre of the room is occupied by a number of people, may be estimated from the following considerations:

"*First.*—The direction of the currents of air from the human body is, under ordinary circumstances, upward, owing to the heat of the body. The velocity of these currents is small, but it may be estimated as being certainly not less than one inch per second. This current is an assistance to upward and an obstacle to downward ventilation.

"*Second.*—The heat from all gas flames used for lighting tends to assist upward ventilation, but elaborate arrangements must be made to prevent contamination of the air by the lights, if the downward method be adopted.

"*Third.*—In large rooms an enormous quantity of air must be introduced in the downward method, if the occupants are to breathe pure and fresh air. The whole body of air in the room must be made to move uniformly downward; for if at any point this be not the case, the products of respiration will rise at those points, and, diffusing, contaminate the air which is coming down to be breathed. The uniform rate of descent should certainly be not less than three inches per second, in order to overcome the ascensional tendency of the currents from respiration, the heat of the body, etc., which implies that, for every 100 square feet of floor area, at least 900 cubic feet of fresh air are to brought in per minute. As the floor of the Hall and galleries of the House contain 12,927 square feet, it follows that the amount of fresh air required would be 193,500 cubic feet per minute, or about three times the amount which is found to give satisfactory results with the upward method.

"*Fourth.*—In halls arranged with galleries the difficulty of so arranging downward currents that on the one hand the air rendered impure in the galleries shall not contaminate that which is descending to supply the main floor below, and, on the other hand, the supply for the floor shall not be drawn aside to the galleries, is so great that it is almost an impossibility to effect it.

"For these and other reasons, the board are of the opinion that the upward method should be preferred. In the upward method there are two special difficulties to be met in halls of this kind. The first is dust, derived mainly from the shoes of the occupants. This, becoming dry, is ground into fine powder, some of which is kept floating in the air by the upward currents. By careful supervision, and by the use of carpets which can be easily detached and frequently shaken, as is done in the English House of Parliament, this evil can be so much mitigated as not to be noticed.

"The second difficulty is due to the discomfort produced by perceptible currents of air. The cause of this is insufficient area and improper position of the openings for the admission of fresh air. If the area of openings be too small, the air must pass through them with too great velocity in order to obtain the required quantity. In a hall liable to be so fully occupied as this, there are few points at which fresh-air openings can be placed the current from which will not impinge on some part of the body of some occupant, and if it does so impinge the velocity should not exceed two feet per second, in order to avoid sensations of draught. The supply of air for the House should be, as we have seen, from 600 to 1,200 cubic feet per second, whence it follows that the total area of openings should be nearly 500 square feet. It is desirable to diminish the effect of these openings as much as possible by placing at least a part of them at points where the currents will not reach a person for several feet, or until they have become somewhat diffused. In attempting to effect this it is very important to remember the law of the adhesion of gases to surfaces, and it is from omission to do this that a large part of the discomfort of members of the House has arisen. It should be distinctly understood that the board states these general principles only as applicable to large assembly halls where a number of people are gathered in the centre of the room, for under other circumstances some of them do not hold good."

The small fan, *E*, shown in Fig. 28, was originally connected with the space immediately over the hall, it being supposed that at times the wind was deflected from the central dome in such a way as to blow down through the louvred openings into this attic, which openings were the only means provided for the escape of foul air. The result of the use of this aspirating fan, in addition to the rarefaction of the air produced in the Hall by the force of the aspirating shaft or chimney, was such that there was a constant tendency for air to flow into the Hall from the surrounding corridors, and whenever a door was opened the direction of the current through it was always inward. These currents had such strength that it was found necessary to place screens opposite the doors to break their force. The air in the corridors was more or less impure and offensive, as it communicated freely by large stairways with the basement and cellar, in which were water closets, bath rooms, a large restaurant with its kitchen, and the engine rooms. The large sewer, which came beneath the building, was unventilated and untrapped.

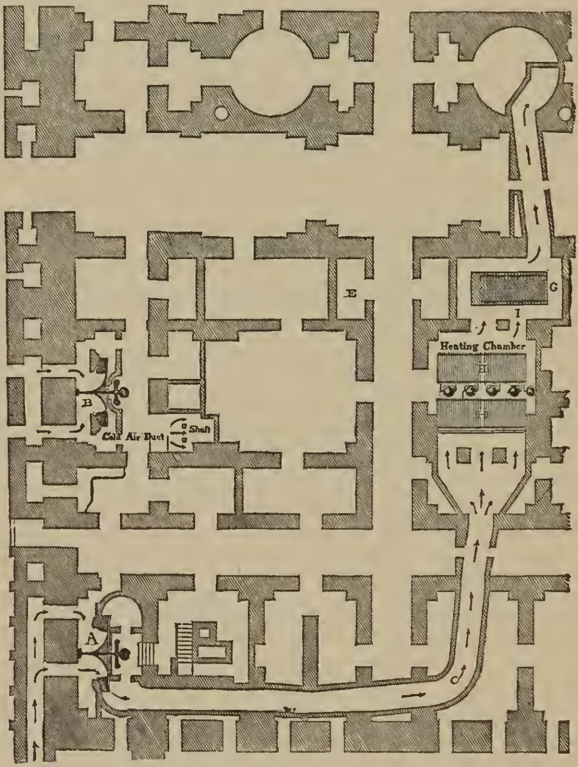


Figure 28.—PLAN SHOWING AIR DUCTS, ETC., IN CONNECTION WITH HEATING APPARATUS, SOUTH WING, U. S. CAPITOL.

A.—Main Fan for Hall.
B.—Small Fan for Committee Rooms.
G.—Evaporator and Mixing Chamber.
H.—Heating Coils.

The result of all this was that various unpleasant odors were at times perceptible in the Hall, and were attributed to almost every cause but the right one. This aspirating fan is now connected with the corridors, as shown in the figure, and the result has been very satisfactory.

The total area of clear opening for the admission of fresh air on the floor of the Hall is about 300 square feet, and in the galleries about 125 square feet. The total area of openings in the ceiling for the discharge of foul air is about 670 square feet, being three times as much as is necessary. This is, however, a matter of minor importance, since the amount of flow is practically controlled by the louvres.

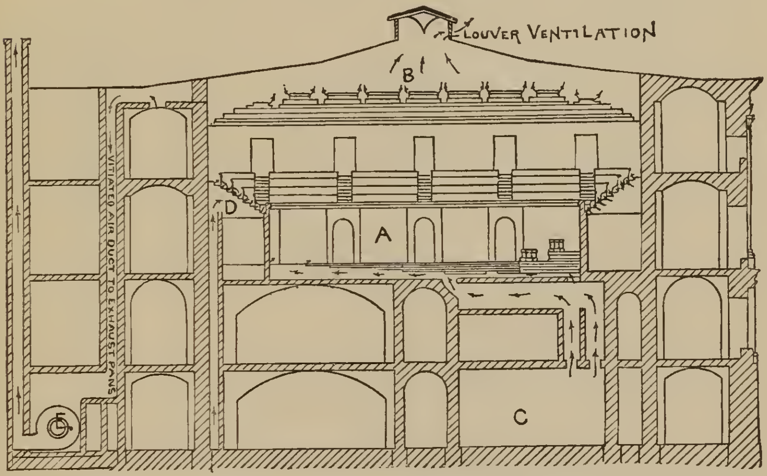


FIGURE 29.—TRANSVERSE SECTION THROUGH SOUTH WING, U. S. CAPITOL.

A.—Main Hall.
B.—Space over Hall.
C.—Main Fresh-Air Duct.
D.—Fresh-Air Supply to Galleries.
E.—Exhaust Fan.

Through the courtesy of Mr. Lannan, the Engineer of the House, I am able to present a table of data (see page 128), showing the working of the apparatus during the month of February, 1881. It will be found interesting to compare this table with the table following, which shows the condition of the working of the apparatus under the old system of exhaust fans in November and December, 1877, after some of the recommendations of the board had been carried out and a considerable improvement effected.

The results obtained are still better demonstrated by the results of some air analyses, made at the request of the writer, in January, 1880, by Dr. Charles Smart, U. S. A. After the House had been in session

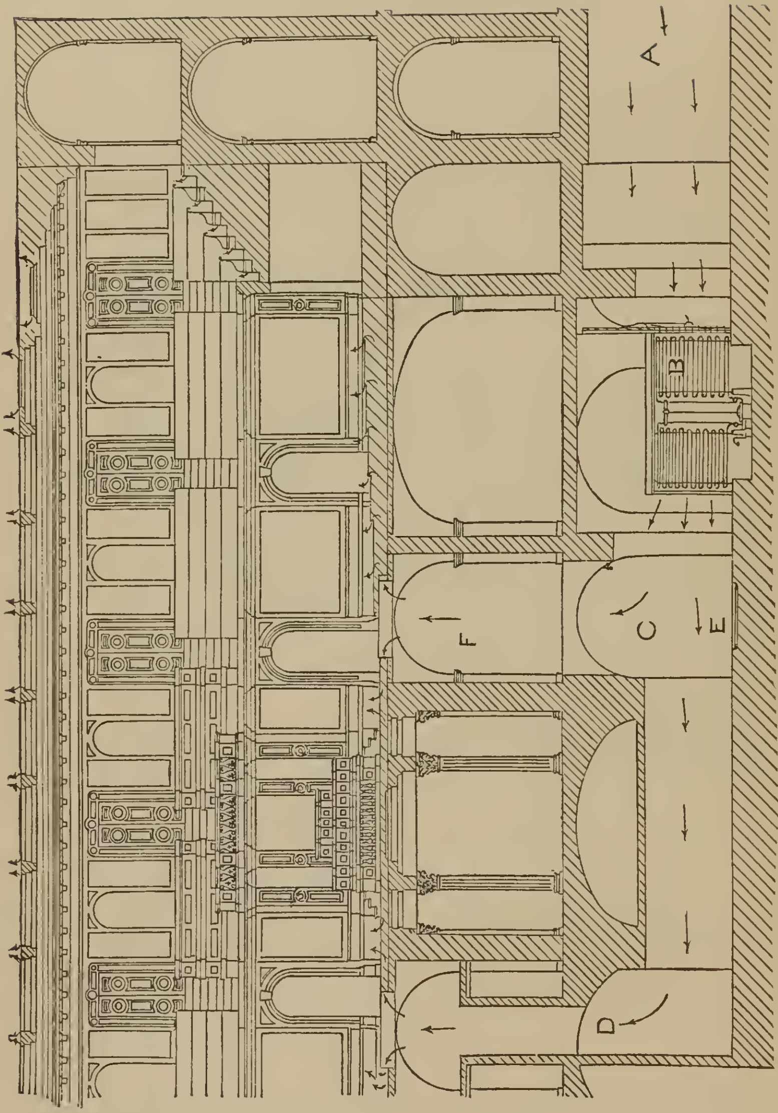


FIGURE 30.—SECTION THROUGH AIR DUCTS AND HEATING APPARATUS OF SOUTH WING, U. S. CAPITOL.

A.—Cold-Air Duct.	*D.*—Fresh-Air Shaft.
B.—Heating Coil.	*E.*—Evaporator.
C.—Mixing Chamber.	*F.*—Fresh-Air Shaft.

3½ hours, with 250 persons present on the floor and 300 in the gallery, the proportion of carbonic acid present in the air at the level of the desks was found to be 7.67 parts per 10,000.

As a portion of this carbonic acid was derived from the underground duct, the amount of carbonic impurity is really not excessive. It shows, however, that the distribution of the fresh air in the Hall is not as prompt and uniform as it should be, since with the amount of air passing into and out of the Hall, and the number of persons present, the amount of carbonic impurity present should not have exceeded 6.3 parts per 10,000.

The Hall of the House of Representatives is a room 139 by 93 feet, and 36 feet high, with galleries and retiring rooms beneath them, which reduce the area of the floor to 113 by 67 feet. This room is surrounded by corridors and committee-rooms, so that all its walls are internal walls, and it is lighted entirely from above by a skylight which extends over the greater part of the Hall. Beneath it is a basement story, 20 feet high, and beneath this again is the cellar or crypt, in which the ventilating apparatus is placed. The plan of this cellar floor is given in Fig. 28, for which, as well as for the other illustrations of the Hall, I am indebted to the courtesy of Mr. Edward Clarke, the architect of the Capitol. The fresh-air supply is taken from a point on the lower terrace about 200 feet from the building, by means of a low tower open at the top and a tunnel, to the large fan. This tunnel has only been in use two years; prior to that the air was taken directly through an area and window in the re-entering angle of the building next the fan. It has been found by Dr. Smart as the result of careful chemical analysis, that the air in its passage through this tunnel has its proportion of carbonic acid increased about one-half of one part in ten thousand.

The fan is 16 feet in diameter and was intended to supply at 60 revolutions per minute 50,000 cubic feet of air against a resistance of about half an inch of water column, and when running at from 100 to 120 revolutions to give 100,000 cubic feet of air, which was supposed to be the maximum amount required.

OBSERVATIONS RELATIVE TO THE MOVEMENTS OF AIR, TEMPERATURE OF THE SAME RELATIVE HUMIDITY, ETC., AT THE HOUSE OF REPRESENTATIVES, FOR THE MONTH OF FEBRUARY, 1881.

Date, 1881. Feb'y.	TEMPERATURE. Outside at M. 12.00	TEMPERATURE. Outside at P.M. 4.00	TEMPERATURE. In the Hall. During Session. Hig st	TEMPERATURE. In the Hall. During Session. L'w st	TEMPERATURE. In the Hall. Lowest during Night.	TEMPERATURE. At Louvres above ceiling during Session.	HYGROMETER. Temperature. Dry Bulb.	HYGROMETER. Temperature. Wet Bulb.	HYGROMETER. Relative Humidity.	Revolutions of the Fan.	AIR MOVEMENT. In the Duct. Velocity of ft. per minute.	AIR MOVEMENT. In the Duct. Volume in cub. ft. per min.	AIR MOVEMENT. At the Louvres above Ceiling. Velocity of ft. per minute.	AIR MOVEMENT. At the Louvres above Ceiling. Volume in cub. ft. per min.	Average number of Persons in the Hall.	Cubic feet of Air per minute per person.	WIND. Velocity in miles per hour.	WIND. Direction.	Weather.	Barometer.	REMARKS.
1	21	21	70	69	65	90	70	55	32	52	665	49.875	534	64.080	550	91	7	N.	Snow	30.10	Outer row of gas jets above ceiling lighted. Inward current at gallery doors.
2	10	14	70	69	63	69	69	53	27	52	645	48.375	465	55.800	650	74	8	N. W.	Fair	30.44	
3	15	20	70	69	62	70	70	54	28	50	610	45.750	420	50.400	750	61	8	"	"	30.34	Inward current at gallery doors.
4	21	26	70	69	62	70	70	55	32	57	685	51.375	440	52.800	800	64	9	"	"	30.38	
5	22	27	70	69	64	70	70	55	32	59	708	53.100	448	53.760	800	66	10	"	"	30.58	
Sund. 6																					
7	28	34	70	69	58	71	72	57	34	57	680	51.000	445	53.400	800	64	4	E.	"	30.82	
8	36	39	70	70	64	71	70	58	44	61	708	53.100	437	52.440	700	76	6	"	Cloudy	30.60	
9	42	46	70	70	66	72	71	59	45	94	1065	79.875	490	58.800	1700	47	4	N.E.	"	30.40	Joint Session of the two Houses counting the electoral vote for President and Vice-Pres't. All gallery doors open.
10	52	58	70	70	65	72	70	61	57	62	690	51.750	398	47.760	750	69	2	S.	Clear	30.08	
11	48	52	70	69	67	71	69	58	48	59	643	48.225	390	46.800	700	69	4	E.	"	30.30	
12	59	58	70	69	66	71	69	57	43	60	676	50.700	410	49.200	700	72	16	S.E.	"	29.00	
Sund. 13																					
14	30	33	70	69	65	70	69	56	39	60	707	53.025	457	54.840	600	88	10	N.W.	"	30.48	
15	33	38	70	69	65	71	70	58	44	60	695	52.125	395	47.400	700	74	4	S.	"	30.61	
16	46	50	70	70	67	71	69	56	39	59	660	49.500	404	48.480	800	62	12	N.W.	"	30.24	
17	33	38	70	70	68	71	70	56	36	59	677	50.775	402	48.240	700	72	7	"	"	30.60	
18	41	46	70	69	61	70	69	57	43	58	653	48.975	447	53.640	800	61	14	S.	Cloudy	30.38	Inward current at gallery doors.
19	47	44	70	69	67	71	68	57	47	59	680	51.000	437	52.440	500	102	9	N.	"	30.20	
Sund. 20																					
21	42	44	70	69	68	71	70	57	40	61	705	52.875	430	51.600	700	75	14	N.W.	Clear	30.27	
22	41	46	70	69	67	72	70	58	44	59	658	49.350	500	60.000	900	55	9	S.	"	30.31	Strong inward current at gallery doors.
23	42	40	70	69	68	71	69	56	39	61	710	53.250	417	50.040	700	76	9	N.W.	"	30.10	
24	23	27	70	69	68	71	69	54	31	61	713	53.475	428	51.360	900	59	6	"	"	30.47	
25	39	44	70	70	69	72	70	56	36	59	662	49.650	433	51.960	800	62	10	"	Cloudy	30.30	
26	42	42	70	69	68	72	71	58	41	60	690	51.750	415	49.800	700	74	8	E.	Clear	30.47	
Sund. 27																					
28	52	48	70	69	68	90	68	58	51	60	685	51.375	457	54.840	900	57	8	N.W.	Rain	27.58	Outer row of gas jets lighted.

Average relative Humidity	$39\frac{67}{100}$
" Revolutions of Fan per minute	60
" Volume of Air carried to the Hall by each revolution of the Fan	868 cubic feet,
" " " " " " each minute	52.094 "
" " " " " " " for each person	67

TABLE OF OBSERVATIONS ON TEMPERATURE AND MOVEMENTS OF AIR IN THE HOUSE OF REPRESENTATIVES, MADE BY WILLIAM LANNAN, CHIEF ENGINEER, IN 1877.

Date.	Revolutions of fan.	Velocity of air in main duct per minute.	Velocity of air through openings in ceiling into attic per minute.	Out-door temperature.	Temperature of air in main duct.	Temperature of air in shaft ascend to floor.	Temperature of air in Hall of Representatives.				Temperature of air in attic.
							Speaker's desk.	North side.	West side.	East side.	
		Feet.	Feet.	°	°	°	°	°	°	°	°
Nov. 17, 11 o'clock..	84	830	175	56	56.5	63	65	65.5	64.5	65.5	68.5
Nov. 17, 1 o'clock..	78	776	210	61	60.5	68	69.75	70.5	69	70	75
At 11 o'clock the hall contained 150 people; at 1 o'clock tolerably filled.											
Nov. 19, 11 o'clock..	76	760	205	41	43.25	72.75	66	64	66	64	68
	76	794	240	42	49	66	68	68.5	68	67.5	73
Nov. 20, 11 o'clock..	76	776	205	42	......	68	65	65	64	65	65
Nov. 20, 1 o'clock..	76	770	235	46	......	65	67	68	67	67	69.5
At 11 o'clock 100 people in hall; at 1 o'clock moderately filled.											
Nov. 21, 11 o'clock..	76	800	230	38	....	79.5	69	66.5	69	66.5	64.75
Nov. 21, 2 o'clock..	76	810	230	42	......	79.25	71	71.69	71	70	70
At 11 o'clock 150 people in hall; at 2 o'clock moderately filled.											
Nov. 22, 11 o'clock..	76	822	230	47	......	74	67	67	68	68	65
Nov. 22, 2 o'clock..	76	778	230	48	......	78	71	71	71	72	70
Nov. 23, 11 o'clock..	76	790	205	52	......	75.5	69.5	69.75	69.5	69.5	69
Nov. 23, 2 o'clock..	74	791	225	55	......	76	72.66	73.5	72	72	72
Nov. 27, 11 o'clock..	54	590	200	48	......	71.5	68	68	67.5	68	72
	55	619	210	50	.....	79	72.5	71	72	71.5	72
Nov. 30, 11 o'clock..	58	582	230	30	......	88.5	72	72	72	73	66
Dec. 1, 11 o'clock..	58	607	190	34	......	73	68	68	70	69	66
Dec. 1, 2 o'clock..	74	750	212	37	......	78	74	72	74	73	72
Dec. 3, 11 o'clock..	52	570	210	38	......	78.5	68.5	69	68.5	68	65
Dec. 3, 2 o'clock..	60	620	220	41	......	71	72	72	72	73	71
Dec. 4, 11 o'clock..	66	600	210	38	......	72	69	69	68	68	66
Dec. 4, 2 o'clock..	56	543	220	44	......	71	72	73	73	72.5	70
Dec. 5, 11 o'clock..	56	653	190	49	......	64	69.5	69	69	69	68
Dec. 5, 2 o'clock..	76	750	205	57	......	68	72.5	73	73	72	72
Dec. 6, 11 o'clock..	62	703	218	41	......	69.5	68	67.5	68	67	65
Dec. 6, 2 o'clock..	48	648	205	44	.....	73	70	70	69.5	71	69.5
Dec. 7, 11 o'clock..	54	620	180	39	......	71	69	68.5	67.5	68	65
Dec. 7, 2 o'clock..	46	560	160	42	......	74.5	72.5	73	72	72	71
Dec. 10, 11 o'clock..	60	681	180	38	......	73	68	67.5	68.5	67.5	64
Dec. 10, 2 o'clock..	58	601	190	44	......	73.5	70	71	71.5	71	70
Dec. 11, 11 o'clock..	60	405	160	40.5	......	72.5	68.66	68.5	68.5	68.5	68
Dec. 11, 2 o'clock..	76	733	190	53	......	73	72	72.5	72	72.5	72
Dec. 12, 11 o'clock..	58	589	160	50	.....	67.5	70	69.5	69	69.5	68
Dec. 12, 2 o'clock..	60	638	175	54	......	71	72.5	72	72	72	72
Dec. 13, 11 o'clock..	56	636	170	49	......	69	68	67.5	68	67.5	66
Dec. 13, 2 o'clock..	60	654	170	52	......	70.5	71	71	71	71	70
Dec. 14, 11 o'clock..	63	739	198	43	......	70	69	69	69	69	67
Dec. 14, 2 o'clock..	64	820	214	46	......	69	72	72	71.5	71.5	70
Dec. 15, 11 o'clock..	76	807	250	42	.....	71.5	.....	....	....	....	67
Dec. 15, 2 o'clock..	76	838	210	51	......	73	....	....	....	....	71
Jan. 3, 11 o'clock..	75	795	......	26	......	60	64	62	64	63	......

Exhaust fans in operation.			Exhaust fans not in operation.
182	N. E. cor.		150
202	S. E. cor.		171
162	S. W. cor.		140
183	N. W. cor.		165
140	Middle skylight.	N.	120
140		E.	135
150		S.	112
143		W.	120

CHAPTER IX.

THEATRES—THE GRAND OPERA HOUSE AT VIENNA—THE OPERA HOUSE AT FRANKFORT-ON-THE-MAIN—THE METROPOLITAN OPERA HOUSE, NEW YORK—THE MADISON SQUARE THEATRE—THE CRITERION THEATRE—THE ACADEMY OF MUSIC, BALTIMORE.

As a rule, theatres are like churches, in one respect at least, namely, that they have insufficient and unsatisfactory arrangements for ventilation. They almost invariably become overheated when the audience is large, while the stage is, as a rule, cold and exposed to draughts. The difficulties in the way of obtaining satisfactory results are much the same as those in large legislative halls, and are to be overcome by much the same methods.

Of late years much more attention has been paid to the ventilation of opera houses and theatres by architects, and some very good results have been obtained, and the best of those of which I have personally seen and tested the results I propose to notice in this chapter.

Probably no theatre in the world excels the Grand Opera House at Vienna in the extent and completeness of the special arrangements for securing ventilation, and in no theatre of the same size, and under similar climatic conditions, have better results been obtained.

The heating and ventilation of this building were arranged by Dr. Böhm, who is now the medical director of the Hospital Rudolfsstiftung, in Vienna, and have been described and illustrated in several of the German text-books.

The clearest description, however, is given in a report by M. M. Demimuid and Herscher, which appears in the "Mémoires de la Société des Ingénieurs Civils," and from which I have translated the following account, and copied, with some omissions, the figures illustrating it. The plan and section of so much of the building as is necessary to show the ventilation of the audience hall are given in Figures 31 and 32. The letters mark the same features in each figure and have the following meaning:

A.—Fresh-Air Chamber.
B, *C*, *D*, *E*.—Heating Chambers.
G.—Tubes for Fresh Cold Air.
H.—Foul-Air Shaft.
S.—Fresh-Air Fan.
U.—Foul-Air or Aspirating Fan.

The building measures 397 x 299 feet, and the theatre itself will contain about 2,700 persons. The ventilation is produced and regulated by two fans, as will be seen on the plans—the lower one for propulsion, the upper for aspiration. This last is also aided by the heat produced by the great chandelier, which has ninety burners. The heating is effected by steam, and the air enters the hall at a temperature of from $63\frac{3}{5}$ to 65 degrees F., the points of entrance being at the floor and in the risers. Each gallery and compartment of the theatre, including the stage, has an independent supply duct and independent means of heating, so that the amount of supply and the temperature can be regulated for that portion irrespective of the rest. The velocity of the entrance of the air is between one and two feet per second. The lower fan is a helix, devised by Prof. Heger, of the Polytechnic School of Vienna. It measures 11½ feet in diameter externally, and has a capacity of 3,531,658 cubic feet of air per hour, the ordinary figure being from 2,825,324 to 3,001,907 cubic feet, corresponding to 1,059 cubic feet per head per hour. The aspirating fan, in the upper shaft, is a simple helix, and the engineers referred to think that it is of little use. Both of these fans are operated by an engine of 16-horse power. There are two fresh-air shafts of supply, each being 19½ x 13 feet.

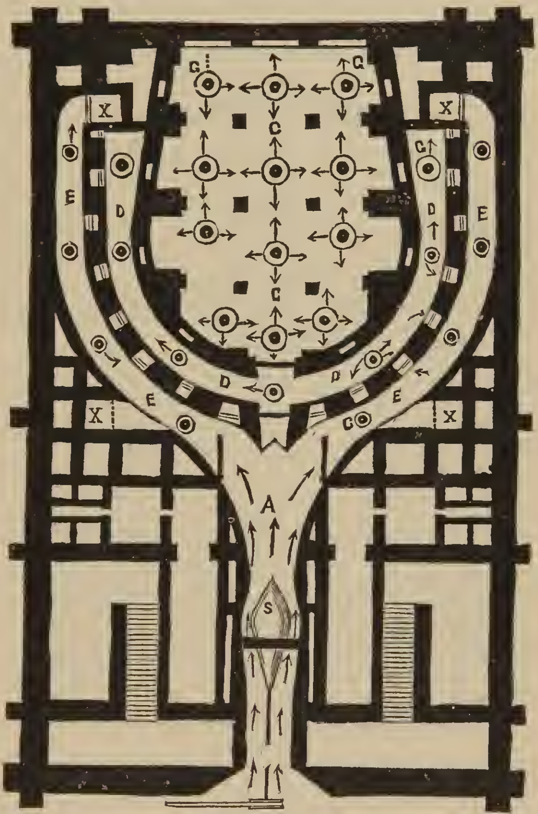


FIGURE 31.

From these the air passes into a basement chamber, where, in warm weather, sprays of cold water are made to play. From these it passes to the lower fan, the air duct from which is 48½ square feet in area. This duct passes below the centre of the theatre into a large space having the same extent as the main hall. The space is divided into three stories. The lower story is divided into distinct chambers, corresponding to the orchestra chairs, dress circle, the galleries, etc. The second stage contains the heating coils, which are composed of 59,058 feet of tubing of 1-inch interior diameter, containing steam at a pressure of five atmospheres. The upper story is the mixing chamber. It will be seen by Figure 32 that the fresh air may pass directly from the lower to the upper floor, or mixing chamber, through tubes about three feet in diameter, without passing through the heating coils at all. These tubes are valved, and can be opened or closed to any extent. The foul air passes out through the shaft shown in Figure 32, which is 13½ feet in diameter. The floor surface occupied by spectators is 14,608 square feet, the capacity of the hall is 388,482 cubic feet, and the combined area of the fresh-air inlets into this hall is 807 square feet.

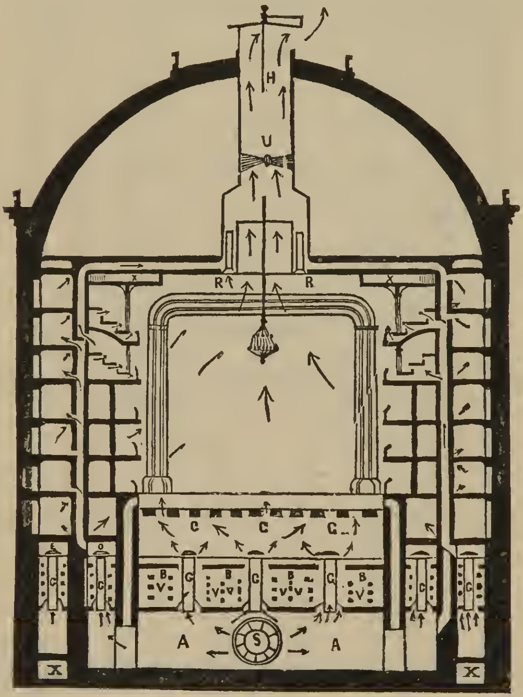


FIGURE 32.

In addition to these ample provisions for the supply and removal of air, Dr. Böhm has also provided, in this building, means for the control and regulation of the whole apparatus from one central office, which forms, as it were, the brain to the machine. By means of electricity the temperature in different parts of the house can be observed in this office of control, and here also are levers which control the valves which regulate the air supply, both hot and cold.

During an operatic performance, the superintendent of heating and ventilation is on duty in this office, and sees that all parts of the house receive their due supply of fresh air and are kept at a proper temperature.

The result has been extremely satisfactory, and I am assured that the expense incurred by these elaborate arrangements has been much more than repaid by increased attendance on the part of those who would not go to an ordinary theatre because of the discomfort produced by overheating and foul air.

In connection with the heating and ventilating arrangements of the Vienna Opera House should be mentioned those of the new Opera House in Frankfort-on-the-Main, which are arranged upon essentially the same system, although it is claimed with improvement as to details, more especially as regards the supply of air to the galleries. The apparatus in this building is designed to supply warmed and moistened air sufficient for two thousand persons. The warming is effected by steam, the boilers for this purpose being in the cellar of a building placed on the opposite side of the street and connected with the opera house by means of a tunnel passing beneath the pavement. There are two of these boilers, each having about 540 square feet heating surface, and supplying steam at from six to nine pounds pressure. The radiators in the heating chamber beneath the audience hall and stage are the usual pipe radiators, and furnish 10,800 square feet of radiating surface, two-fifths of which is devoted to the stage and adjoining rooms.

The fan for propelling the fresh-air supply is a helix, nine and a half feet in diameter, of the same pattern as that used in the Vienna Opera House, and it furnishes in winter 2,800,000 cubic feet of air per hour, or 1,400 cubic feet per person, being an increase over the amount allowed in Vienna. The maximum capacity of the fan gives about 2,400 feet per head per hour, and this is intended to be the summer supply. Provision is made at the point of entrance of the fresh air into the building for cleansing, moistening and cooling it by drawing it through sprays of water.

The general results obtained by the apparatus are very good, and are especially well marked in hot weather, when a good audience can always be collected in this building, because of its coolness, freshness and comfort. I have not been able to obtain any detailed results of observations of the work actually done as regards movement of air and heating or cooling it, but as the whole is under the direction of a competent engineer, it is to be hoped that we shall some day have a detailed report which will furnish data of much scientific interest and value.

The Metropolitan Opera House in New York City is another large building of this class in which excellent results have been secured, so far as heating and ventilation are concerned. The apparatus in this case was devised by Mr. Frederic Tudor, and I take the following description and illustrations, by permission, from the *Sanitary Engineer* of December 6 and 13, 1883, having personally verified their accuracy:

"The principle involved is 'plenum ventilation,' the object being to

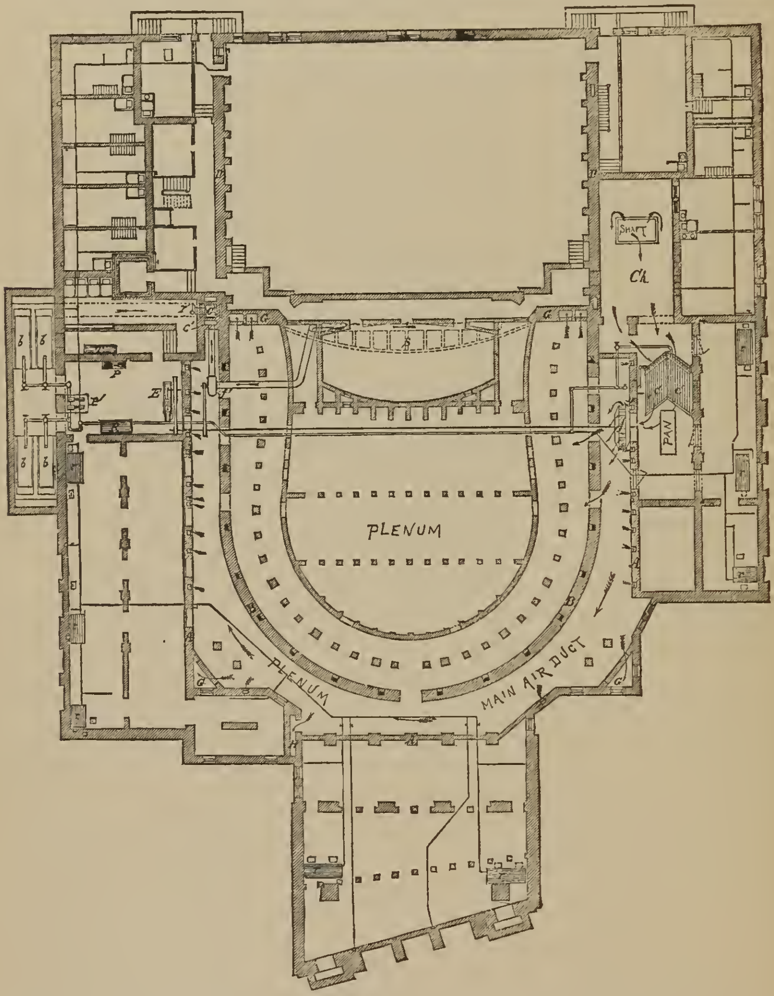


FIGURE 33.—METROPOLITAN OPERA HOUSE, NEW YORK CITY.—GROUND PLAN.

have an excess of air entering the building to that which is leaving it by the regularly provided foul-air outlets. The result of this is to have a pressure within the building slightly in excess of that of the air without the walls, so as to insure an outward current through crevices of doors or windows or through accidental openings. To accomplish this in a practical manner, a blowing engine must be used, and the supply of air must be almost unlimited. To this end the shaft (at the right of

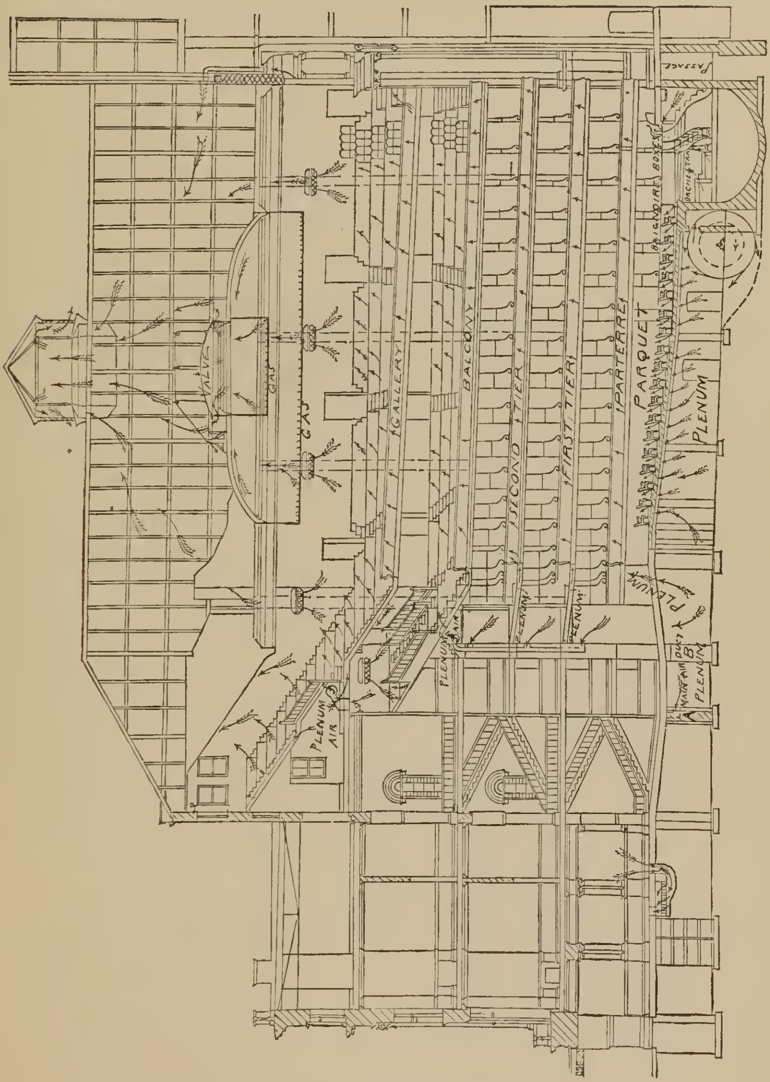


FIGURE 34.—METROPOLITAN OPERA HOUSE, NEW YORK CITY. LONGITUDINAL SECTION.

the stage on the ground plan), seven feet by ten feet six inches (73.5 square feet), was provided in connection with the fan, *f*. Air is taken in at a height of seventy-five feet from the ground, and sixty feet below the top of the boiler chimney, and as remote therefrom as possible, being on the north or Fortieth Street side of the house. After the air has been drawn down through the shaft it enters a settling chamber, forty-eight feet by twenty feet, with a height of ten feet, thence it is drawn through the heating coils, *C C*, or passed around through the swinging doors, as shown, to the fan. From this point onward there is now a condition of *plenum*, and all of the building within the walls *A A A* and the proscenium walls is supposed to have a pressure slightly in excess of the outside atmosphere. From the fan the general course of the air is through the main air duct, between the walls *A* and *B* in the basement in the direction of the arrows, but all the basement within the walls *A A* is subject to the same pressure. From the basement room immediately under the auditorium floor the air is admitted through many 4 x 4-inch openings made through the brick arches into the space between the arches and the floor. From this space, the air for the occupants of the parquet chairs passes through the risers of the floor steps on which the chairs are set. In these risers are arranged openings continuous at their face, but of peculiar construction, and covered with No. 16 galvanized iron perforated with $\frac{1}{10}$-inch holes, a detailed drawing (Fig. 37) and description of which is given on page 139.

"The air which supplies the boxes is carried from the main air duct in the flues in the wall *A* to the spaces between the floors and ceilings, as shown on transverse section, and discharged at the edges of the tiers at *a a*. Its course is then upward and backward, to the flues in the wall *B*, which have an exhausting power derived from the heat of the gas jets under the hoods in the balcony and family circle, and from the gas light, when used, in the private parlor, immediately behind the chairs, a detail of which is shown in Fig. 38, page 140. The balcony and family circle receive air through the large flues *G G* at the ends of the main air ducts in the proscenium wall and through the flues *G G* and *H* in the wall *A*.

"The air is discharged into the spaces shown, formed by the ceilings of the box parlors on the second tier and by the ceiling in the angle of the balcony at the walls. It is then distributed to the edge of the balcony and family circle at *a a* and through a 2 x 4-inch hole at the back of every chair in the risers of the galleries. By this means every stationary chair in the house has air admitted to it.

"The outlets for foul air are those already mentioned in the boxes, and which are shown in the wall *B* (ground plan), and those in the proscenium wall at the ends of the gallery and balcony. Such of the flues in the wall *B* as were cut off by the extension of the balcony and family circle toward Broadway (an after-consideration) are carried in a galvanized-iron pipe within the air space under the balcony to other flues in the wall *B* on the right and left. Into these flues connect the openings from the hoods over the gas lights in the balcony and gallery, each hood being a register.

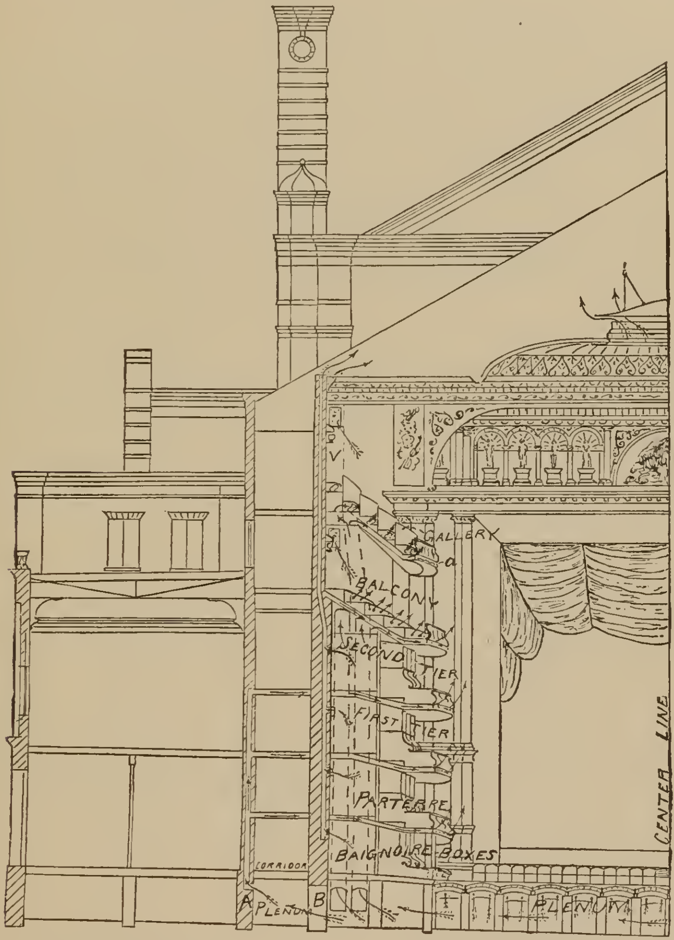


FIGURE 35.—METROPOLITAN OPERA HOUSE, NEW YORK CITY.—TRANSVERSE SECTION.

"In the highest part of the gallery ceiling, in the rear, are five registers, under two of which there are clusters of gas brackets, the aggregate area being twenty square feet. In the balcony ceiling there are likewise *four* registers of fifteen square feet, under each of which there is a cluster of gas brackets. The foul air from these are likewise carried to the wall *B* in galvanized ducts.

"In the centre of the dome-shaped ceiling is the main controlling valve to the ventilation. It is circular, sixteen feet in diameter, and admits of any adjustment by the rising and lowering of the bell-shaped disk by the winch shown in the longitudinal section.

"By the adjustment of this valve, the pressure within the house may be regulated and the condition of plenum maintained under varying conditions of the speed of the fan made necessary by the climatic changes.

"All the foul-air outlets in front of the proscenium wall open into the space between the ceiling and the roof, and reaches the outside atmosphere through the louvred ventilator at the apex of the roof. This ventilator has openings equal to 108 square feet, with louvre boards of peculiar construction and an inner shield to prevent the admission of snow or rain.

"The stage has separate ventilators at the roof and in the side walls, and is warmed by direct-radiation coils on the back wall. By this means a difference of pressure is kept between the house and the stage when the curtain is down; enough to belly the latter slightly toward the stage. The rising of the curtain then allows air to pass from the house to the stage ventilators.

"The method of managing the warmth of the house in cold weather has been to keep the temperature at about 78° in the day time, by slow movements of the air at a temperature of about 80°. The object of this is to warm the walls and all objects somewhat above the temperature required when the building is occupied, so as to prevent radiation or the loss of heat from the bodies or shoulders of people in evening dress to the walls or surrounding objects. Then in the evening, when the building is to be occupied, the temperatures in the air duct are dropped to 70°, and the air sent in full volume through the house. The result is, the thermometers show a higher temperature in the auditorium than that at which the air enters through the openings, etc., due presumably to heat received from the walls, floors and warm passages. Then, as the evening advances and the effect of the heat from the gas and from the human body increases, the entering air is lowered to 67° in the main duct. With this latter temperature in the duct at 9.30 P. M., the temperature throughout the house ranges from 70° to 73° F., according to location, being coolest in the balcony and gallery.

"On the evening of November 7, at 9.30 P. M., and after the air in the duct had been lowered to 68°, the temperature at the wire of the parquet circle, a little to the right of the main entrance, was 70°. At the floor of the parquet, at the same place, it was 70°. Half way round the house to the left, breast high, it was 74° ; in the same position, to the right, it was 72°; in the first tier, centre box, on a chair, it was 73°; in the salon, behind box, 74°; and for other parts of the house it was: Balcony, centre (failure) ; right, 71°; left, 72°. Air entering through openings, right, 70°; left, 70°. Family-circle (gallery), centre, 70°; left, 72°; right, 72°. First tier, lobby, outside wall *A*, 70°. In air duct, last experiment, 11 P. M., dry bulb, 67°; wet bulb, 53°. The temperature in the box salon (74°) is accounted for by the radiation from the walls, as the house had been kept at near 80° during the day. The increase to 74° at the left of the parquet is unaccounted for.

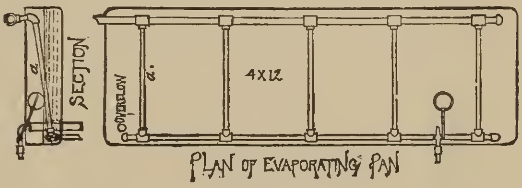


FIGURE 36.

"In the coil chamber, between the coils *C C* and the fan, is placed an evaporating fan, to regulate the hygrometric state of the incoming air. The difference of temperature between a dry and wet bulb thermometer, in the main air duct, being maintained at from fourteen to sixteen degrees lower for the wet bulb.

"To regulate the hygrometric state of air after it leaves the coils, the evaporating pan (marked *Pan*, on the ground plan), a detail of which is shown in Figure 36, was devised. The pan proper is of iron, 4 feet by 12 feet, and 12 inches deep. It is suspended directly in the warmest currents of air, and is furnished with a ball-cock to keep the level of water constant. Within the pan is a brass coil of *one*-inch pipes, *a*. This coil has a steep incline, as shown in the section, Figure 36. The elbow of each inclined pipe is at the level of the top of the overflow pipe, but the other end rests on the bottom of the pan. By raising or lowering the water in the pan, more or less of the coil is submerged, and more or less moisture driven off into the air.

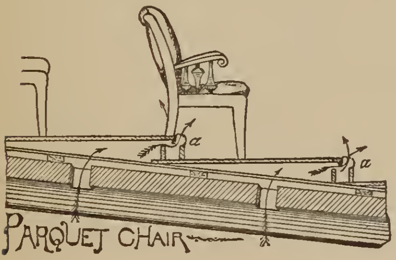


FIGURE 37.

"Figure 37 is a detail of the manner of admitting air through the auditorium floor. The arches are of brick, and the whole space between them and the wooden floor is filled with warmed air, which enters through a baffle, *a*, that runs the whole length of the steps. The iron molding at the edge of the step is perforated with small holes to admit the air in a spray, and its shape is designed to direct and diverge the jet over 180 degrees of a circle, the object being to admit a large quantity of air imperceptibly.

"Figure 38 is a section and plan of the private boxes, of which there are 120. The air is carried through the floors from the flues in the wall *A* (as before mentioned), and delivered at the edges of the box balconies, as shown. To each two boxes is arranged a vent flue, as shown on plan. A special corner-register face is arranged in each box, with a septum extending inward, as shown, to intercept light, etc. In each register is fixed a small bell-mouthed funnel, extending a short distance into the flue. Under this funnel is an argand gas burner, the products of combustion of which are drawn into the flue directly and not allowed to escape into the salon. The heat which accompanies the combustion may also be a help to the draught of the flue.

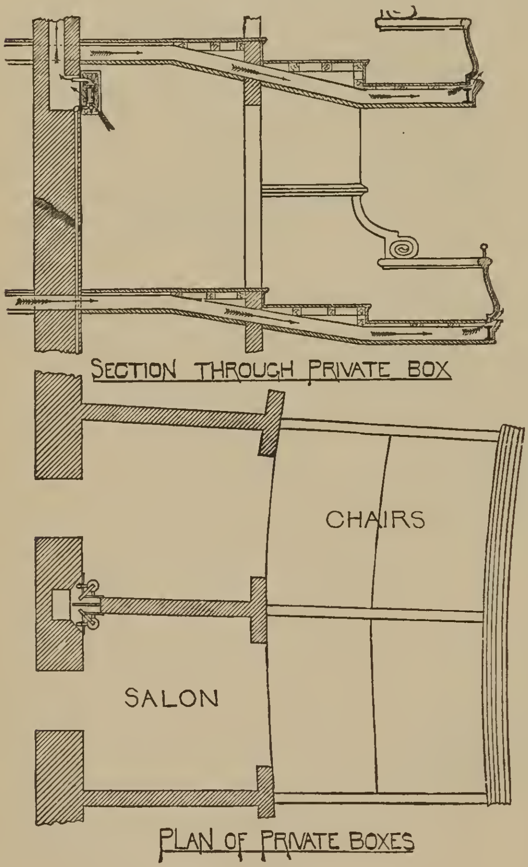


FIGURE 38.

"Figure 39 represents the special ventilation of the footlights. At the edge of the stage at *S*, on the ground plan, is a system of flues connecting with the exhaust fan *F*. This fan is driven from the main shaft and discharges its air into a flue at the side of the boiler chimney flue.

The object is to prevent the heat and products of combustion from rising over the stage. The detailed section, Figure 39, is through one of eleven short flues, 8 x 12 inches, which connects the space formed by the metal reflector and the metal edge of the stage, with a main or trunk flue, which in turn connects with the fan. This space, within which the three gas pipes for the different colored lights lie, is divided into as many sections as there are branch flues, and within each flue is a damper, *d.* These dampers are set and fixed with the use of a water-gauge, so as to give a difference of pressure in each flue of one-half inch water pressure, the object being to get an equal pressure or draught into all the openings at the edge of the reflectors, over the gas chimneys. The condition of plenum within the house caused by the main fan also assists this system.

"The main fan is 12 feet 6 inches in diameter by 45 inches in the width of the blades, and delivers about 70,000 cubic feet of air per minute when it is running 100 revolutions per minute. The fans used are the 'Sturtevant' make, and are driven by one of the Hartford Engineering Co.'s engines, 14 inches diameter by 21 inches stroke, and which is situated at *E* in the engine room. The main fan is driven in directly from the engine, the speed of the engine being regulated to suit the velocity required for the fan. The dressing-rooms are warmed by direct radiation, a heater being placed in each room.

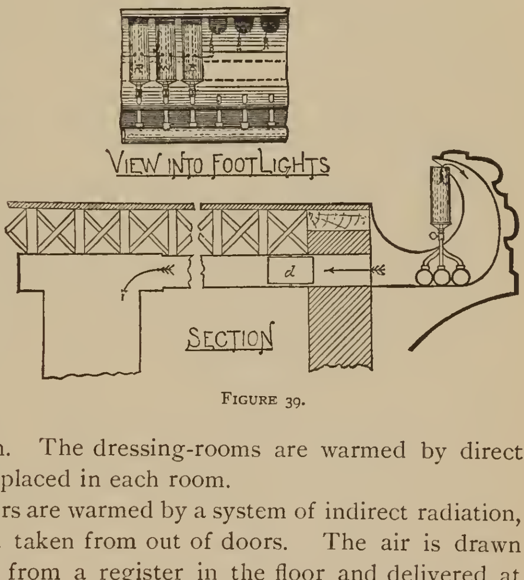


FIGURE 39.

"The halls and corridors are warmed by a system of indirect radiation, but the air supply is not taken from out of doors. The air is drawn down in one leg of a flue from a register in the floor and delivered at another register nearly over the radiator. This may be seen in the longitudinal section. The reason for doing this is to leave the corridors clear and unobstructed, otherwise direct radiators would be used. In the parlors, toilet-rooms, offices, etc., vertical radiators of the 'Reed' pattern, made by the H. B. Smith Co., are used. The indirect heaters, excepting the large coils, are 'Gold' pin radiators, *centre connection.*

"Mr. Tudor furnishes us with the following note of a test of the volume of air supplied to the auditorium of the Metropolitan Opera House on the evening of December 7, 1883:

"Used Casella's anemometer. Time, 9 to 9:30 P. M. Current measured in main inlet shaft, two and one-half feet above the ceiling of the settling chamber. Speed of fan revolutions, 100 per minute at 9 P. M.; 92, at 9:30 P. M. Approximate average speed, 96. Velocity of current of *four* tests: *first*, 980; *second*, 977; *third*, 918, and *fourth*, 890. Average, 941, by cross area of shaft (73.5 square feet) = 69,163 cubic feet entering the building, equivalent to an entire change of the air once in a period of from ten to eleven minutes.

"The air-meter was kept constantly in motion in a horizontal plane within the down shaft while recording, it being first carried around close to the walls of the shaft, then zig-zag across it from wall to wall."

Another theatre in New York in which special attention has been given to ventilation is the Madison Square Theatre, a good description of which, prepared by Mr. W. G. Elliot, was published in the *Sanitary Engineer* for October 15, 1880. From this description I take the following extract:

"From near the rear end of the gable a square wooden cupola rises to a height of about twenty feet above the roof. Each side of this is provided with two sliding shutters operated by ropes from below. These openings face the cardinal points of the compass and are used in pairs; thus, if the wind is southwest, the shutters at the south and west are opened while the others remain closed. The shaft into which these open is square, six feet in section, and extends downward behind the scenes to the cellar.

"This inlet shaft, as well as many of the larger ducts, is constructed of smoothed pine boards, sheathed in places with paper, and having few bends.

"Suspended in it, point downward, is a conical-shaped cheese-cloth bag, about forty feet deep, through which the incoming air is filtered. A chamber at the bottom of the inlet is provided with a number of shelves inclined at an angle of about forty-five degrees, upon which, in summer, ice is placed to chill the air. From this point, the main duct, diminished to a diameter of four feet, connects at the axis with a Sturtevant fan, eight feet in diameter, with blades three feet by eighteen inches, and making 150 revolutions per minute. The periphery of this wheel, moving at the rate of about two-thirds of a mile per minute, forces the air at a high velocity into the delivery duct, five feet by three feet, in which is placed another mass of ice. Four tons are used every night, two in the delivery and two in the inlet duct.

"The delivery duct is of brick, and is branched into six sheet-iron pipes, each two feet in diameter. Two of these are again subdivided in two and open into four brick chambers, four feet square. Three steam radiators are placed in each chamber to supply heat in winter.

"The auditorium is divided into four sections of ninety seats each, and every individual seat is supplied from the chambers by four-inch tin pipes, ninety of which are connected with each chamber.

"Two of the two-feet flues from the main brick delivery duct have not yet been accounted for. Each of them is subdivided into three smaller sheet-iron flues, one set of them passing up the side wall on the right and the other on the left of the house, and opening into the auditorium through several 4 x 10-inch orifices just beneath the first balcony, ten feet above the floor, and also through a number of two-inch openings in the lower edge of the balcony, and also across the entire front of the stage.

"Through the former openings in summer the cooled air is poured into the house to reduce the temperature and to furnish a supply for respiration.

"The dome chandelier, together with each wall bracket, are encased in glass, and pass the products of combustion into separate flues connected with the exhaust fan. The proscenium boxes and the elevated orchestra chamber have their separate inlets and outlets, while the galleries are as well supplied as the parquet.

"Another Sturtevant blower, eight feet in diameter, located upon the roof near the middle of the building, is employed to exhaust the foul air.

"A wooden flue, four feet by five feet, descends from this at a sharp incline to the floor of the attic, there dividing at right angles into two smaller ducts three feet square. These are again subdivided in two, twenty-four inches square. Two of them withdraw foul air through six 6-inch pipes in the ceiling under both sides of the first balcony.

"The two others pass down to the lobby, opening into two 20 x 24-inch registers in the wall, and located near the floor on each side of the main entrance.

"An additional register, five feet in diameter, is placed in the ceiling at the rear of the upper balcony, and connected by means of a large flue with the main exhaust duct.

"One other feature remains to be mentioned, viz., the ventilation of the footlights. Behind the row of jets is placed a strip of sheet metal, six inches high, resembling corrugated iron, the corrugations being large enough to form small niches, or "pulpits," as they are called, in each of which a jet is situated.

"Behind this sheet a hollow space communicates with an eighteen-inch flue, extending each way from the centre to the side of the stage, and thence through hollow iron columns to the exhaust ducts. A metallic hood projects over the top of the row of lights. The products of combustion are drawn back over the top of the niches and downward into the flues of the exhaust.

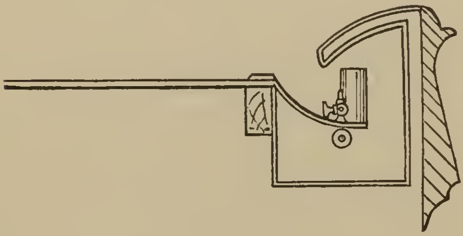


Figure 40.

"The action here seems to be complete and satisfactory.

"Observation showed that at about 9:30 P. M. the driving fan was making 150 revolutions and the exhaust 82 revolutions per minute. The temperature of the air in the main delivery duct, just beyond the ice, was 70° F.; that in the lower part of the theatre 80° F.; at the outlet of the main exhaust flue 86° F.; while that of the outside air was 85° F. At the close of the play the temperatures were about the same—that in the lower part of the theatre being 82° F.; at the outlet of the exhaust flue 88° F.

"The current of cool air entering through wire screens in the risers beneath the seats was very perceptible, but not sufficiently strong to create unpleasant draughts. No foul and overheated air could be detected in the upper gallery, and, in fact, the variation in temperature and purity of air in different parts of the house was so slight as to be almost unnoticeable. The exhaust registers in the lobby, as well as that in the upper balcony ceiling, showed a strong inward current. Those

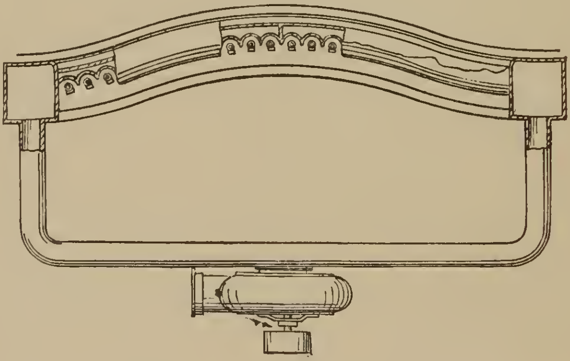


Figure 41.

in the first balcony, however, were not so active. The fresh-air inlets about the 'horseshoe' and under the first balcony were doing their duty well.

"The fan in the basement is able to deliver *actually* the required theoretical quantity of 1,000,000 to 1,250,000 cubic feet an hour, or about 1,500 cubic feet to each person in the auditorium. The upper fan can withdraw this amount at 100 revolutions, while it could easily run to 200 when speedy change of air might be desired.

"In conclusion, I would say that I think much better results could be obtained if the exhaust fans were run at a higher rate of speed than on the evening in question. A considerable amount of energy is wasted by the sharp angles at some of the junctions in the exhaust and to a less degree in the forcing system.

"There has also been some bad calculation of the necessary relations of large to smaller diverging flues. The general effect of the system is exceedingly good, however, and an immense improvement over any of the theatres in the city with which the writer is familiar.

"Unfortunately, I have been unable to make this description complete by a statement of the velocity of the inlet and outlet flues, the total quantity of air introduced, and by an analysis of the air in the room after the audience had been in for some length of time."

The Criterion Theatre, in London, presents the peculiarity of being situated entirely beneath the level of the street, so that the floor of the theatre is over thirty feet below the level of the sidewalk. It occupies an area of eighty by fifty feet, with a height of twenty-seven feet, and accommodates about 1,000 persons. The main purpose of the building is that of a large restaurant, with a grand hall on the upper story, and in many respects it is an excellent model for buildings of this class.

The architect, Mr. Thomas Verity, has given a description of it, with illustrative diagrams, in No. 5 of the Transactions of the Royal Institute of British Architects for 1878–9, under the title of "The Modern Restaurant," and these diagrams, which are for the most part self-explanatory, are herewith reproduced. Mr. Verity describes the ventilating arrangements as follows:

"For the ventilation of the theatre a fan is provided, four feet six inches in diameter, worked by a direct-acting steam engine. It draws its supply down a series of air shafts, formed in the main eastern wall, and forces it into an air chamber formed under the floor of the theatre. From this chamber shafts are carried up in the walls to diffuse the fresh air at different levels around the whole space. In addition to these shafts, branch distributing channels are provided for a supply of air for the stalls and the pit. Hot-water pipes arranged in coils are fixed in the chambers, in order that the air supplied may be warmed when found necessary before its distribution. A water spray is also fixed in the main cold-air supply for cleansing the air.

"For the extraction of the vitiated air from the body of the theatre, a centre perforation, about five feet, is provided; this is in direct communication with a powerful extraction shaft, four feet by three feet, running up the entire height of the building. In order to increase the power of this shaft, the waste heat from the grill stove and the products of combustion from the sun-burner that lights the theatre, are carried

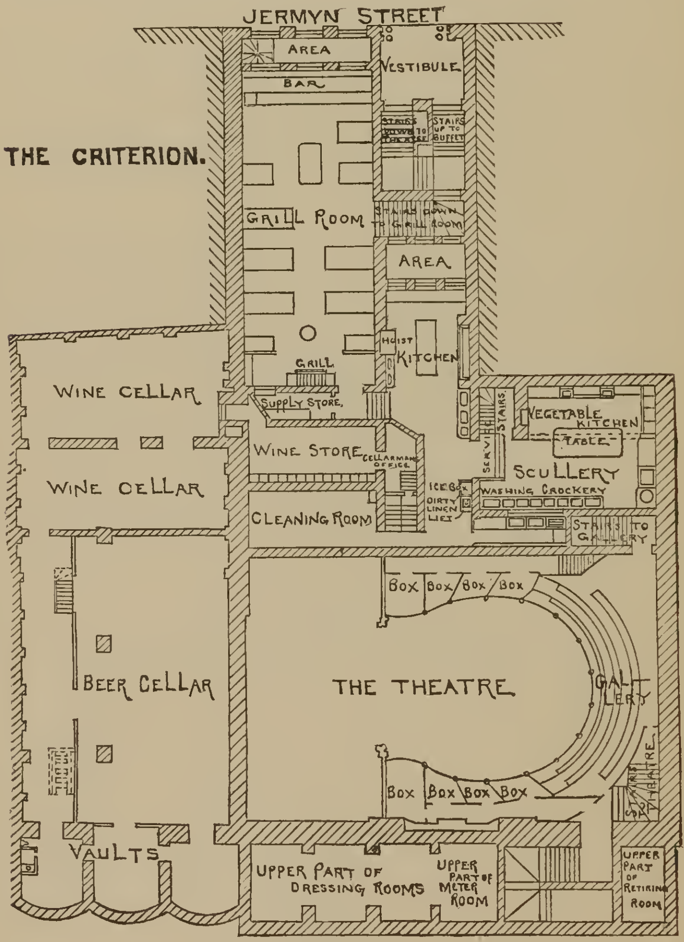


FIGURE 42.

up the centre in independent wrought-iron pipes. At the gallery level and also at the back of the stage four other extraction shafts are provided. It is found, when this apparatus is in full working, that the

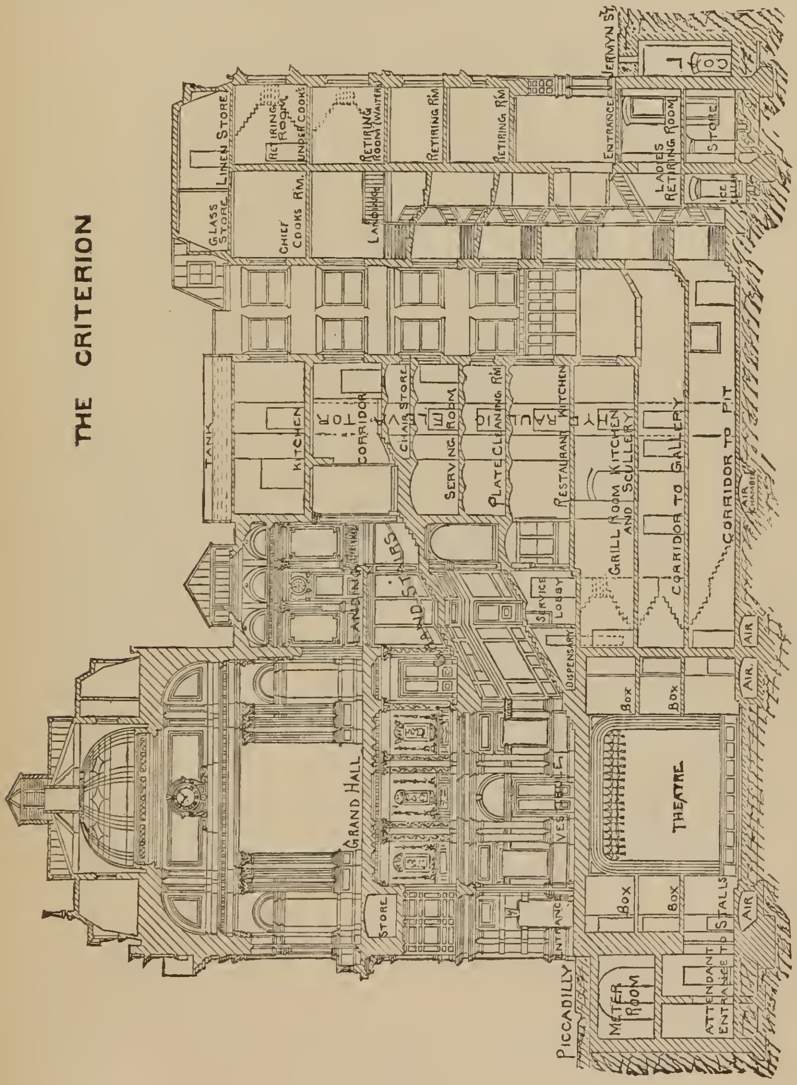


FIGURE 43.

amount of air supplied and extracted is equal to the entire renewal of the cubical contents of the theatre from five to six times per hour.

"The ventilation arrangements for the large hall consists of a series of inlets of fresh air around three sides of the hall, in direct communication with the chamber already described. The vitiated air is removed through the sun-burner, and the perforations around it communicate with a main extractor formed over the dome."

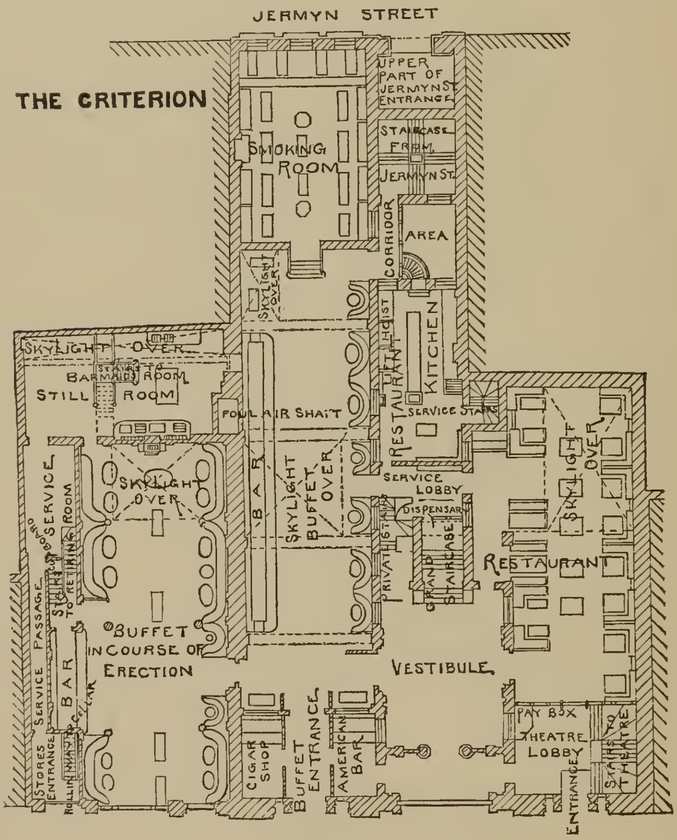


FIGURE 44.

From personal observation, I can say that the ventilation of the theatre with an audience of about 600 was fairly satisfactory. Toward the close of the performance the temperature of the room had increased rather beyond the limits prescribed by comfort, but, on the whole, the results were better than I had anticipated, and show that the resources of modern engineering are fully competent to secure good ventilation under circumstances which, at first sight, would seem quite adverse to such a result.

It is of interest to note that, after much controversy with the Metropolitan Board of Works, it was decided that the floor between the theatre and the restaurant formed a sufficiently fire-proof division to enable the two to be considered as separate buildings. Licenses are not allowed to a theatre and restaurant in the same building.

The corridors and staircases leading to the theatre are entirely fireproof, and it will be seen that they are entirely distinct from the restaurant part.

Another building of this class which is worthy of note in this connection is the Academy of Music, in Baltimore. In this building the special object of the architects seems to have been to make the method of ventilation serve also to improve the acoustic effects, or, at all events, not to interfere with them. To this end it is desirable that the sound of the actor's voice shall, as far as possible, go with the main current of air rather than across or against it. For this purpose they bring the supply of air for the audience mainly from the stage, warming it when necessary by means of ordinary steam coils. Before the audience assembles the hall is warmed by hot air admitted through two openings in the parquet, which openings are usually closed before the performance commences. The exit of foul air is intended to be by a large shaft from the centre of the ceiling, the opening of which is controlled by a valve. To secure distribution of the air, large exhaust flues are placed in the walls, opening below in the rear of the galleries and communicating above with the exhaust shaft above referred to. A sketch of the arrangement is given by Mr. Neilson, one of the architects of the building, in the second biennial report of the State Board of Health of Maryland, printed in 1878.

The acoustic properties of this theatre are excellent, and the supply of air to the galleries is fairly good. The only force available for securing change of air for the seats on the lower floor is practically the heat furnished by the audience themselves, the supply of air being insufficient, and the great mass of the fresh incoming air curving upward as it enters from the stage. An objection to this direction of the main current is, that in case of fire the direction of the draught would be from the stage, with its mass of highly combustible material, toward the audience, so that the mass of smoke and flame would be whirled directly among the people.

For this reason it has been suggested that the main outlet should be from the stage, and not from the auditorium. The *American Architect* of December 24, 1881, contains a letter from Mr. C. A. Walton, an architect, in Toronto, suggesting that in addition to the brick party wall and iron drop curtain, which are usually agreed upon as desirable, "there should be a large sheet-iron chimney flue or duct commencing at the ceiling of the 'fly' or scenery-room above the stage, and extending up to a point eight or ten feet above the highest point of the roof; said flue at bottom to have an area of not less than one-tenth of the area of ceiling aforesaid, and to taper inward to five or six feet diameter at the top, and to be placed directly over the centre of the stage to carry off the smoke, heat and flame from a possible fire below."

Upon this the editors of the *Architect* observe that the plan is not a new one, having been already put in use, and point out that the stage ventilator might be found ineffective at the critical moment because of the momentary non-existence of a draught in it. They suggest, however, "that this defect might be entirely obviated and something effected toward counteracting the air currents, which habitually flow from the stage toward the auditorium, if the heated and vitiated air should be led from the ventilator of the auditorium, by means of ducts laid between its ceiling and roof, up to this more elevated stage ventilator. If, in addition to this, properly arranged heating coils and fans are put in place and used at every performance, we see no difficulty in establishing and maintaining an air current which shall always flow through the proscenium arch from the auditorium and toward the stage, thus negativing one of the most prolific causes of danger."

It will be seen that the requirements of a theatre are, among other things: good ventilation and heating, good acoustic qualities, and security against fire, and that these are, to some extent, incompatible under any arrangement yet devised. I confess that I do not understand how the plan proposed by the editors of the *Architect* can insure the result which they seem to aim at. If air is to be drawn out at the centre of the ceiling of the auditorium, I do not see how this is to produce a current in the reverse direction—namely, from the auditorium toward the stage. The proposition is something like pumping water out of a cistern in order to make it overflow.

The whole matter of theatre construction needs further study, and the great need is for reliable scientific data. Notwithstanding all the capital which has been invested in these costly structures, there are only one or two of them for which any precise data are in existence as to amount of air introduced, its distribution as shown by air analyses, and the relations of these to number of audience, external temperature, wind, etc.

So also as regards acoustic qualities. If there are any existing data as to the audibility of sounds of various pitch, power, and quality in any large theatre when occupied by an audience, I do not know of them. All that we have are the opinions of Brown, Jones and Robinson on the matter, and unfortunately B., J. and R. do not agree among themselves, either as to the facts in the case of any given auditorium or as to the reasons for those facts.

The problem of heating and ventilating a large assembly hall is somewhat simplified, when instead of tiers of galleries rising one above another, as in the opera houses referred to, the room presents merely a single level or slightly sloping floor.

A very good arrangement for a room of this kind is presented by St. George's Hall, in Liverpool, the heating and ventilation for which were arranged by Dr. D. B. Reid in 1854–55. This grand hall measures one hundred and twenty by ninety feet, and is eighty-five feet in height. It has about 1,800 seats on the floor, 350 in the galleries and 200 in the orchestra.

The apparatus designed by Dr. Reid for this hall and the Law Courts connected with it has worked well, and, so far as I can learn, has given satisfaction to the present time.

In one of the courts an attempt was made a few years ago to alter the plans to suit a patent plan, but the result was a failure.

The heating apparatus for this building was designed by Dr. Reid to be in part hot water low pressure, and in part steam.

The water apparatus is intended to be the principal source of heat, and more especially for the great hall and the court and concert rooms. The steam coils are to be used principally for rapidly heating the building, and especially the corridors and smaller rooms, and as auxiliary to the hot-water apparatus.

The supply of air is determined in part by aspiration, but mainly by four fans, which were specially employed to diminish and neutralize draughts and currents at the doors of the court rooms, and to insure that whatever currents might exist at these points should be outward and not inward.

The memoranda furnished by Dr. Reid in connection with his directions for the use of the apparatus are worth remembering by all who have charge of such machinery. He says:

"Let the external doors used be in unison with the special ventilation required at the Great Hall and the conditions of the weather. Without proper arrangements there, or in the temporary tents used outside on great occasions when the weather is cold and stormy, it is impossible for the arrangements within to compete with the force of the external atmosphere.

"Let changes required during the occupation be anticipated as much as possible, and never made suddenly when great alterations are necessary; the large valves should always be slowly and gradually opened or shut.

"With a temperature ranging from 62° to 68°, according to the quantity of air introduced—with a hydrometer where the dry bulb and the wet bulb of the thermometer used do not indicate more than five degrees of difference—and with a movement where the quantity of air introduced is given by the gentlest possible inclination at all the apertures available, the ventilation is generally brought into the highest and most efficient action.

"Let the precise course to be taken at each special occupation of the building be determined according to the number of apartments to be occupied at the same time, and the attendance expected in each apartment. Then set all the minor valves open or shut, as may be required, so that during the actual occupation of the whole or any part of the building, the movement of the larger valves alone can regulate all the changes that may be necessary.

"Let the cleaning of the whole of the fresh air ventilating channels be carried on systematically, and every portion be inspected periodically at stated periods.

"Let no painting be permitted, except at proper periods, and none be used for warm apparatus, except the hard copal varnish, laid on in the most sparing manner in which it can be applied and retained. More trouble, annoyance, and dissatisfaction with the condition of ventilating works may often be traced to this cause than to any other; excessive painting takes away the freshness and elasticity of the air in an extreme degree, and too frequently gives it the character of being cooked or baked. No practice is so common in some public buildings as painting them *immediately before the commencement of a season of occupation*, to an extent that they do not get over till it is terminated.

"Let the condition of the boilers in use be daily reported, and the highest and lowest temperatures of the water boilers noted, as well as the highest and lowest pressures at which the steam boilers have been used.

"Let the alarm apparatus provided be made known to the attendants at the boiler room, and that any member of the Law Courts Committee, or any inspector, as well as the director, can at once tell whether any boiler is or has been above the allowed temperature, when a fixed place shall have been determined for the magnetic electro-thermometer apparatus explained in the Index of the Diagrams (47).

"Let the general arrangements adopted in the ventilation of the Great Hall, the Courts and the Concert Room, be registered in books provided for the purpose on each occasion when they are used for public purposes, reference being made to the particular diagrams that express the course pursued. Let any special memoranda that may be useful be added, and let these books be registered and kept as the property of the corporation for future reference on all special occasions."

These last recommendations have not been carried out, and I have been unable to find any record as to the amount of work actually done by the fans and heating coils, but the general testimony is to the effect that the results are satisfactory.

An elaborate series of diagrams illustrating the ventilation of this building was published by Dr. Reid in 1855, and forms an atlas folio containing five sheets of drawings and twelve pages of text. This is now rare, and although it is not of much practical value, it is worth securing by the engineer who is fortunate enough to meet with it.

The building of the Union League Club, corner of Fifth Avenue and Thirty-ninth Street, New York City, presents some peculiarities in the arrangement of its heating and ventilation which are worthy of notice.

Through the courtesy of Mr. Tudor, who furnished the apparatus, I am able to give the following diagrams and description, the latter being derived also in part from a personal examination.

This is a five-story brick building, about 150 x 85 feet, and containing 932,000 cubic feet of space to be warmed and ventilated. The apparatus used for this purpose consists of steam coils and radiators to furnish heat, and, to some extent, motive power in exhaust flues, and a fan, 10 feet in diameter, to produce and control the necessary influx of air.

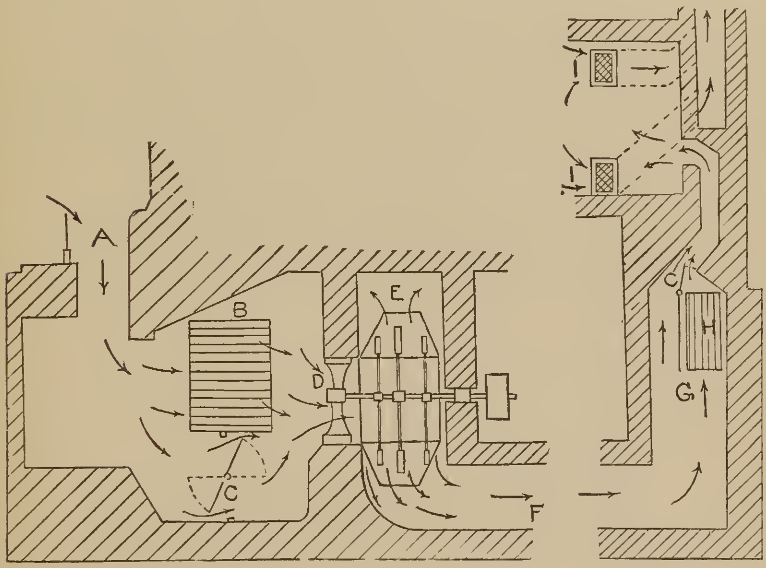


FIGURE 45.

A.—Cold-air Inlet.
B.—Steam Coil.
C.—Dampers.
D.—Inlet to the Fan.
E.—Fan.
F.—Main Duct.
G.—A Branch Duct.
H.—Supplementary Coil.
I.—Outlet Flues.

The general arrangement is shown in the diagrams, Figures 45 and 46.

The fresh air taken from the street level is drawn through a chamber so arranged that it may either be all forced through a steam coil, or a part of it may be allowed to pass below the coil. The layers of cold and warm air thus produced will be thoroughly mixed by the fan, and pass into the space *F*, which is about four feet high and extends under the whole building, forming a large common air chamber whence all the flues obtain their supply. The bottom of this chamber is of concrete, resting on hard, blue clay, and it is intended that the temperature in it shall be from 70° to 80° F. The fresh-air flues connect with it as shown at *G*, being wide enough below to permit the insertion of a small supplementary heating coil, as shown at *H*. The valve *C* shown, connected with the upper corner of *H*; is controlled by a rod passing to the room to which the flue leads, and it will be seen that the occupant of the room can thus regulate the temperature of the incoming air to suit himself without diminishing the quantity. The movable arm on the register which regulates this valve is shown in Figure 46, which represents a section through one of the conversation rooms of the club, indicating positions of outlets and inlets.

In the arrangement of the fan ducts in this building there must be a very considerable loss of power from contracted inlet and from the arrangement of the air chamber, which virtually forms a sudden expansion to the delivery duct. With the fan making 130 revolutions per minute, Mr. Tudor states that he obtained a movement of 33,000 cubic feet per minute, which is slightly in excess of his calculation as to what is required.

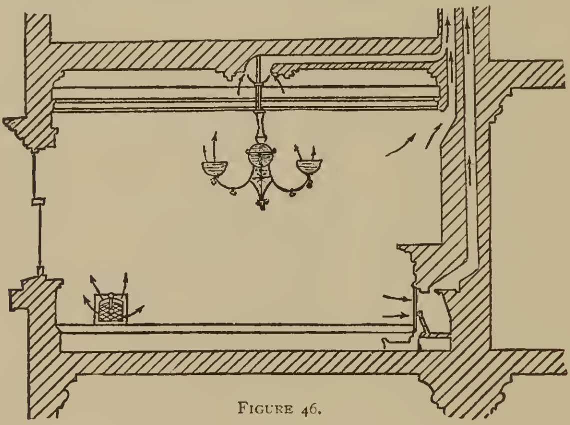


FIGURE 46.

Certain rooms, such as water closets, servants' rooms, etc., obtain their whole supply of air from the corridors, and have outlet flues specially heated, the intention being to secure a constant flow of air from the halls into the rooms. They are, in fact, the only outlets for the large supply of air which is furnished to the staircase halls.

The amount of air supply and heating surface has been calculated on the assumption that 3,000 cubic feet of air per hour per person shall be allowed, except in the audience hall, where about 1,000 cubic feet per head per hour is provided for.

It is also assumed that during the day—that is, until 5 P. M.—about 100 persons will be in the building, and that in the evening 1,000 persons may be present, although from 500 to 600 will be the usual number.

The fan is intended to have a capacity of about 2,000,000 cubic feet per hour. To heat this air, about 9,000 square feet of radiating surface are provided, one-half being in the large steam coil between the fan and the street. This coil will be heated by steam at about 60 pounds pressure, and will therefore be of much higher temperature than an ordinary steam radiator.

This high temperature, which will probably be over 280° F., is relied upon to make up what would otherwise be a deficiency in heating surface. The exhaust steam from the engine which runs the fan and the elevator is turned into the heating apparatus, causing a back pressure of about 10 pounds.

One of the special difficulties in this building is to provide a sufficiency of fresh air for the audience hall or theatre.

The accompanying cuts, Figures 47 and 48, show the plan and section of the theatre. This room measures 79 x 43 x 24 feet, containing 80,000 cubic feet, and has a floor area for seats of 36 x 50 feet, accommodating about 300 persons. The total area of inlet is 23 square feet, of which 15 square feet are in the perforated panels in front of the stage, and the remainder at the sides above the stage, as shown in the plan. At a velocity of 4 feet per second for the incoming air, this would give for each person a little over 1,000 cubic feet per hour.

Through the courtesy of the architects, Messrs Peabody & Stearns, I have been able to compare the original specifications for the heating and ventilation of this building, as prepared by them, with the modified specifications upon which the contract was finally based. The work to be done is essentially the same in each, viz., to force 30,000 cubic feet of air into the building per minute, said air being at a sufficient temperature to heat the building to 70° F., with the thermometer at 15° below zero outside (or, as in the modified specification, at 10° below zero outside). The essential difference between the two sets of specifications consists in the amount of heating surface to be supplied. In the original specifications, it is required that there must be at least one square foot of radiating surface to 65 cubic feet of space, which would make about 14,300 square feet of radiating surface to the entire building, and, also, that it is to be arranged to run at a pressure of five pounds, or less when desired. The modified specifications require that "the total area of heating surface is to be equivalent in condensing power, in combination with other parts of the apparatus, to 31,164 lineal feet of 1-inch pipe, or

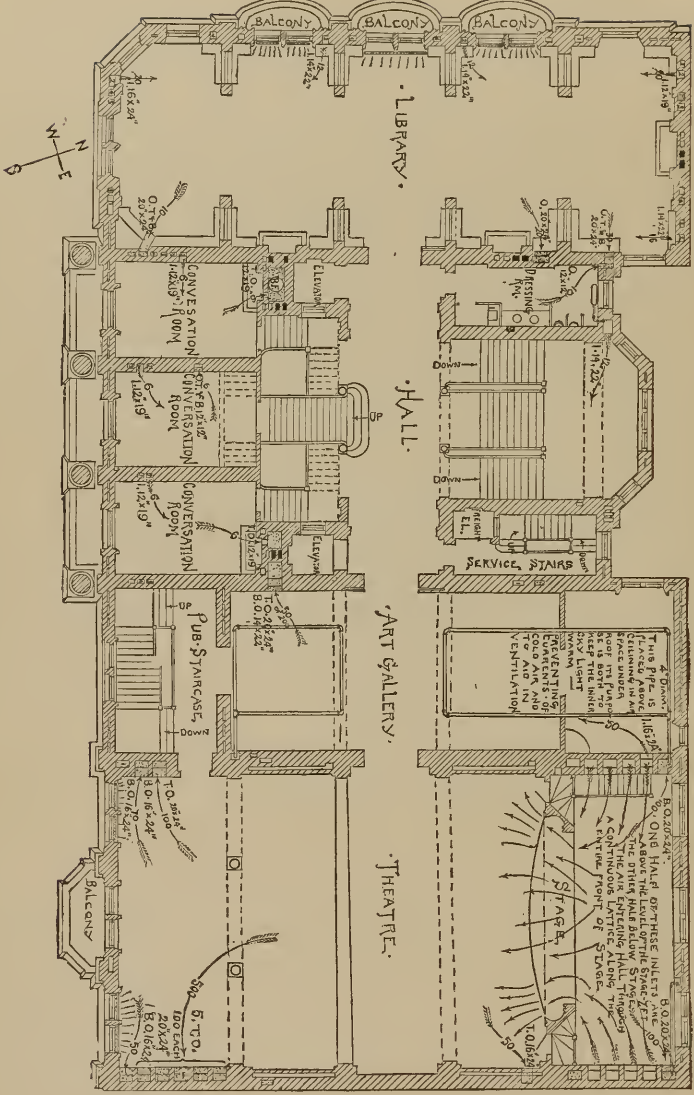


Figure 47.—SECOND FLOOR PLAN, UNION LEAGUE CLUB,

AS HEATED AND VENTILATED BY F. TUDOR & CO.—PEABODY & STEARNS, ARCHITECTS.

I.—Inlet.
O.—Outlet.
T.—Top.
B.—Bottom.
.·.·.·.—Foul Air.

The relative distribution of air is shown by the numbered arrows.

9,800 square feet exposed to an atmosphere of 65°," and that the apparatus is to be arranged to work at either high or low pressure.

It will be seen that the plan proposed by Mr. Tudor and accepted by the committee provides for a comparatively small amount of radiating surface, which must be raised to a correspondingly higher temperature. Some of the special difficulties which this involves are done away with by the expedient of placing the greater part of the radiating surface between the fan and the outer air, so that this part of the surface can be highly heated, and the fan can be relied on to secure a thorough mixture of this superheated with cooler air.

So far as the heating is concerned, this plan has proved fairly satisfactory, but the ventilation of the theatre cannot be said to be a success. A sufficient amount of air is not introduced, and that which does come in is not sufficiently distributed.

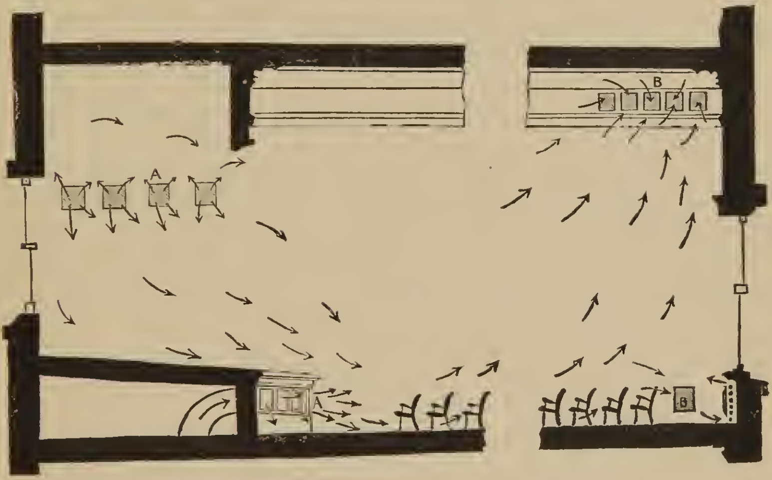


FIGURE 48.

By reference to Figure 48 it will be seen that the seats remote from the stage must obtain very little fresh air.

With reference to the difference as to amount of heating surface called for by the original specifications, and that provided for in the specifications proposed by the contractor, it is to be remarked that it is much better that the amount of heating surface should be specified by the architects, or by an engineer who is not connected with any establishment for the supply of heating apparatus, than to follow the usual rule and let each bidder determine for himself the amount of radiating surface which he will supply.

But the requirement that a certain amount of radiating surface shall be furnished will be of little use, unless the various bidders are satisfied that the amount which is actually put in will be measured by the architect; in other words, that the provisions of the contract will be enforced. The best heating firms will, of course, do what they agree to do, but in bidding they must come in competition with others who are not so scrupulous, and as the measurement of the heating surface actually put in is a precaution very rarely taken by architects, and as this fact is very well known throughout the trade, it follows that bids will be put in which could only be carried out at a loss to the contractor if the work was actually done in accordance with them. Those firms which have patent boilers, or patent radiators, or both, in whose special efficiency they have confidence, will, of course, object to specifications which call for ordinary unpatented boilers and the common tube radiators, while, on the other hand, to specify patent apparatus is to reduce the competition to a single bidder.

Building committees and some architects are apt to think that the easiest way out of this dilemma is to simply require that the building shall be comfortably heated in the coldest weather, and then let each bidder prepare his own specifications as to how he proposes to do it. The result is that the bids are not comparable. Most of the specifications presented are so vague and indefinite as to be practically worthless as an indication of the manner in which the work is to be done, and the committee or person giving out the proposals comes to the conclusion that the only thing to be done is to accept the lowest bids.

The result is, of course, in the majority of cases, that the work is unsatisfactory.

If proper and complete specifications, independent of the interests of any manufacturer, cannot be prepared, and the terms enforced, the best course is to call for no bids, but employ a respectable and honest party to do the work as it should be done, and pay the price.

CHAPTER X.

SCHOOLS.

Of all classes of buildings in the United States, public or private, there are probably none which are in such an unsatisfactory condition, as regards their ventilation, as the public schools. In our large cities they are, almost without exception, overcrowded and insufficiently supplied with air, and for these and other reasons which I need not here specify, they are probably the cause of a vast amount of ill health and premature death, although these results are usually not so direct and immediate that they can be clearly traced. Every intelligent teacher knows that the dullness and listlessness in some pupils, and the irritability and peevishness in others, which are so manifest toward the close of the afternoon session, are closely connected with the gradual accumulation of foul air which has been going on through the day. If, after a brisk walk in the open air, you enter one of our city school-rooms about 3 P. M., you will find an odor which is far from being agreeable, and which, under such circumstances, is the characteristic sign of insufficient ventilation. I have before me the results of the examination of the schools in Boston, New York, Baltimore, Washington, Cincinnati and Rochester, made by competent men, and accompanied in many cases by chemical analyses showing the amount of impurity present in the air. Everywhere the result is the same ; with a change of name of place one report would almost answer for all. It is something like the remark of the old toper about whiskey. He said there was no bad whiskey, although some samples were better than others. In like manner we may say there are no good schools, although some are worse than others. As regards ventilation and overcrowding, probably the New York public schools will average worse than any others in this country, but single instances have been reported in Brooklyn and in New Orleans which are probably worse than anything in New York.

It is not my intention, however, to attempt to criticise individual school buildings, but rather to state as briefly as may be the general principles which should govern the architect in arranging the heating and ventilation of such structures.

Before doing this, however, it may be instructive to consider how far it is proper to hold architects responsible for the defects of such buildings. There has been a good deal of growling at architects lately on the score of their neglect of sanitary matters, and these complaints have come not merely from the doctors and the public at large, but from architects themselves. On the other hand, in the leading journals devoted to architecture in England and America, will be found some of the best and freshest sanitary literature, and to the studies of individual architects are due the majority of the improvements in construction which are really valuable from a hygienic point of view. But the average architect, when called on to design a school building—how will he probably proceed ?

Taking a comparatively recent work on school architecture, which is very instructive and valuable as regards the general plan and arrangement of such buildings, we find, on consulting the chapter on Heating and Ventilation, that the author thinks that carbonic acid is the specially dangerous impurity that is to be gotten rid of, and that this carbonic acid, when cool, falls to the bottom of the room, but as he insists that all the foul-air outlets must be at the ceiling, he expects to carry off the greater part of the poison before it has time to settle. Steam heating, he says, cannot pretend to be of use for schools.

He concludes by remarking that medical men seldom speak or write upon the subject without displaying much scientific knowledge, but that their application of such knowledge is not so successful. "The theory of extraction from the bottom instead of the top may be scientifically and theoretically the best, but it is practically inapplicable to a school-house. * * * Extraction from the bottom requires, from its great friction, so enormous a motive power as to be out of the question, except in buildings of very great size."

The above extracts are sufficient to show how unnecessary a knowledge of the ordinary laws of the physics of gases and of the principles of ventilation is considered to be by this authority, as well as his sublime contempt for those who possess such knowledge. He does not propose any particular plan for ventilation, but says that "the architect should exercise his own judgment, *and should invariably intrust the carrying out of the work to some engineer specially accustomed to the kind of appliances and arrangements proposed to be used.*" This last passage is a solid piece of wisdom, and as such, I have ventured to italicise it.

Is it strange that the school-house architect should blunder when such is his instruction, or that he should fall an easy prey to the first man who calls himself an "engineer," and urges on him the merits of his patent compound, deflagrating, ventilating, lubricating air heater and purifier ?

Within a few years there has been a change for the better, but I am compelled to believe that the majority of architects in this matter go by rule of thumb instead of a satisfactory comprehension of the very simple principles involved, and that, moreover, the thumb aforesaid is not of the right dimensions or proportions.

A good illustration of this appears in some remarks contained in the *Builder* of December 4, 1880, p. 667. The writer says that "he was now engaged in superintending the erection of two schools, one of them to be warmed by Mr. Boyd's hygiastic grates, and the other by Leed's American steam-heating system. * * * Unless the air was heated in a direct manner, just as the atmosphere was warmed by the heat imparted to the earth by the sun, or as the air of a room was warmed by the heat given off to it from the objects warmed by the fire, the principle proceeded upon was wrong. It was necessary to keep to direct radiation; in other words, the radiating points must be in the room to be heated, and not in chambers or places remote from it."

From this it would seem that he is satisfied that steam can be used in heating schools, but he thinks that the heating derived from a coil of steam pipe in a room is of the same character and presents the same advantages as that from the rays of the sun, or from an open fire—which is not the case. Heating by a steam radiator in the room to be heated is essentially a system of air heating, for the true radiant heat from such a body is comparatively small in amount and feeble in effect.

My object in all this is not especially to criticise these authorities or to controvert their dicta, but it is to show the difficulties which will always beset an architect who does not understand physics—the laws of heat, light and sound, and of statical and dynamical hydraulics and pneumatics, and I am very much afraid that some architects do not learn as much of these things as they ought to.

I am by no means advising that every architect should endeavor to make himself an expert on the subject of heating and ventilation, but he ought to know enough of these subjects to see his own ignorance, and to be able to judge of the relative merits of those who do profess to be experts, and who come to him seeking employment—and also, he should know enough, for the sake of his own reputation, not to be dogmatic in his assertions about the merits of this or that method which he has never seen tried and with regard to which he has no scientific data whatever.

In planning a school-house the first things to be considered are the amounts of floor and cubic space and of air supply which are to be allowed each scholar. The class of school-houses which we are considering are those of such size and importance that an architect will be called upon to prepare plans and designs for them. They are usually located in cities, where space is limited, and the amount allowed for their construction will be insufficient to secure first-class work. Under these circumstances the sanitarian who asks for a liberal allowance of fresh air combined with a comfortable temperature and freedom from draughts, will find that if he sets a high standard his views will be promptly condemned as being unpractical. When the plans are in course of preparation the average board of school trustees will approve of any number of flues and chimneys, but when it comes to giving out the heating contract, and some enterprising steam-fitter offers to guarantee perfect heating by placing coils in the school-rooms under the windows, for about one-half the cost of such an apparatus as would do the work properly and furnish fresh air at the same time, the said board will, in nine cases out ten, try the cheap plan, with the usual results.

Let us see what some recent authorities have to say as to the proper amount of air space and air supply for schools. In a report made to the International Congress of Education, held in Brussels in 1880, Dr. De Chaumont discussed these questions fully, and his paper should be consulted as representing the views of European sanitarians on this subject.

Taking, as a starting point, the experiments of Pettenkofer, which show that a man at rest exhales 266 cubic centimetres of carbonic acid per hour for every kilogramme of his weight, and making the necessary allowance for the increase due to movement, speaking, etc., he concludes that a child in the school-room exhales about 346 c.c. of carbonic acid per hour for every kilogramme of its own weight. The average weights of children of different ages being known by Quetelet's tables, and De Chaumont's researches (to which I have referred in a previous chapter) having shown that the amount of carbonic acid derived from respiration should not exceed two parts in ten thousand, if the odor of organic matter is to be avoided, he has from these data computed the following table:

AGES.	Cubic metres of pure air to be supplied per hour.	Cubic air space.	No. of pupils for a room containing 315 cubic metres.
4 years	25.960	8.650	33
5 "	28.890	9.630	30
6 "	31.320	10.440	28
7 "	34.890	11.630	25
8 "	38.510	12.840	23
9 "	41.670	13.890	21
10 "	45.200	15.060	19
11 "	48.200	16.070	18
12 "	53.630	17.880	16
13 "	61.100	20.370	14
14 "	70.060	23.350	12
16 "	92.200	30.730	9
Adults	118.140	39.380	7

It will be seen that the table is based on the assumption that the air in a school-room cannot conveniently be changed oftener than once in twenty minutes, and that therefore the cubic space in such a room should be one-third of the amount of air to be supplied per hour. As a matter of fact, this amount of space is not given in the public schools of any country, because of the great expense which it would involve, nor is it a necessity, since the above calculations are based on a supposed permanent occupancy of the room, as in a hospital ward, whereas the school-room is occupied but a few hours at a time, and can then be thoroughly aired. The following are the dimensions fixed by law in different countries or recommended by those who have given special attention to this subject, the data being derived from De Chaumont's paper above referred to :

Belgium.—By law one square metre of floor space and 4.5 metres in height to each scholar. The Educational League of Belgium, in the plans of its model school, proposes 1.67 square metres of floor space, and 5.75 metres in height, giving 9.6 cubic metres to each pupil.

In Holland the average cubic space per pupil is 3,727 cubic metres ; in 89 schools in Haarlem the average per head is 4.54 cubic metres. In England, in the Board Schools, about one square metre of floor space, and from 3.65 to 4.25 metres in height is allowed for each scholar.

Bavaria prescribes 3.9 c.m. for scholars of 8 years, and 5.6 c.m. for those of 12 years. The public schools of Dresden give an average of 0.7 square metre of floor space, and 4.38 c.m. to each.

In Frankfort the Medical Society advised 1.84 square metres of floor space, and from 8.5 to 9.2 c.m. per head.

At Basle, in Switzerland, 1.45 square metre, and from 4.21 to 4.67 c.m. per head are prescribed. In Sweden in the primary schools 1.52 square metre and 5.35 to 7.55 cubic metres ; in the higher schools 1.58 to 2.17 square metres, and 7.69 to 9.980 cubic metres per head are given.

In New York City from 2 to 3 cubic metres per pupil are allowed theoretically, but the actual quantity is sometimes much less. Dr. De Chaumont is disposed to lay some stress on the question of age and to take the ground that young children require much less air space and air supply than adults, as they produce so much less carbonic acid. He would, for example, put three times as many children of 4 or 5 years of age, as of youths of 15 or 16, in a given room. This seems to me to be very doubtful. The question of amount of carbonic acid exhaled has little or nothing to do with the matter, except in so far as it is an index of the amount of organic matter given off, and it is probable that the difference between the amount of organic matter excreted by a child of 5 and one of 15 is by no means so great as would be indicated by the carbonic acid test. I should allow in a school-room or hospital very nearly the same amount of air supply per head for children of all ages over 5 years. The dimensions of the school-room recommended by Dr. De Chaumont are 10 x 7 metres, and 4½ metres in height, and in such a room he would place from 12 to 53 scholars, according to their ages.

In connection with the paper of Prof. De Chaumont, above referred to, the transactions of this congress contain essays by M. Wazon, a French engineer, and M. Dekeyser, a Belgian architect, upon the methods of heating and ventilating schools. M. Wazon takes 20.5 cubic metres as the allowance of fresh air per hour per head. M. Dekeyser allows from 20 to 30 cubic metres, according to ages.

Prof. W. Ripley Nichols, of Boston, in a report on the sanitary condition of certain school-houses in that city, dated March 23, 1880, fixes as the permissible amount of carbonic acid in school-rooms one part by volume in 1,000, and while tacitly admitting that this is a low standard, says that it is as high a one as can at present be insisted on. "With this amount of carbonic acid there will undoubtedly be more or less of the 'school odor,' especially with a certain class of the scholars. To obviate this entirely would require an amount of fresh air which could not be practically introduced into a building constructed as the Sherwin school is; in case of new buildings a higher standard might be obtained, say 0.8 or 0.9 volumes of carbonic acid in 1,000 volumes of air; but it is doubtful whether this standard could be reached without a larger amount of floor space than the 15 square feet usually allowed."

The amount of carbonic acid which Prof. Nichols actually found in the school-rooms of the Sherwin school varied from 1.43 to 2.29 parts per 1,000.

The standards which I would fix for space and air supply in schools are those given in the report of the special committee on plans for public schools, given in the *Sanitary Engineer* for March 1, 1880, and reiterated in the report of a commission on the public schools of the District of Columbia, dated March 15, 1882, and printed as Mis. Doc. No. 35, House of Representatives, 47th Congress, 1st Session, viz.:

> "In each class-room not less than 15 square feet of floor area shall be allotted to each pupil.
>
> "In each class-room the window space should not be less than one-fourth of the floor space, and the distance of the desk most remote from the window should not be more than one and a half times the height of the top of the window from the floor.
>
> "The height of the class-room should never exceed 14 feet.
>
> "The provisions for ventilation should be such as to provide for each person in a class-room not less than 30 cubic feet of fresh air per minute, which amount must be introduced and thoroughly distributed without creating unpleasant draughts or causing

any two parts of the room to differ in temperature more than 2° F., or the maximum temperature to exceed 70° F."

It must be remembered that the above represents the minimum of requirement, and is based upon the requirements in cold weather. In warm weather, when the incoming air need not be heated, the supply should be as great as open windows and doors can be made to furnish.

The usual requirement of those schools in this country for which the architect will be called in to prepare plans will be that they shall contain from eight to twelve class-rooms, each of which is to accommodate from forty to sixty pupils, and that these are to be arranged in connection with a large central hall in a two-story brick building.

In some cases there will also be required one large assembly room, which is usually placed in a third story. The heating will be effected by furnaces or steam, the tendency being to increase use of the latter. The trouble with furnaces is that they are almost invariably set in insufficient number, and are of too small a size.

To undertake to heat such a school-house as that above described with one or two furnaces is to insure bad ventilation. Not less than four furnaces are necessary in such a building, and these must be of the largest size, giving a large heating surface, costing from four to six hundred dollars each when properly set.

A properly arranged and well constructed steam-heating apparatus for such a building will cost from four to six thousand dollars, depending on the exposure, etc. Cheap steam heating is more objectionable than a furnace. As a rule, school-rooms are overheated, the temperature in winter in our schools ranging usually from 72° to 76°. The rule should be that the temperature should never exceed 70°, and Dr. Lincoln is no doubt correct in his statement that children can be made comfortable at 66° in a well-aired room.

The sensations of the teacher rather than those of the scholars usually govern the regulation of the temperature, and, as Dr. Lincoln remarks, "an interesting lesson may be going on, or a written examination; the mind works well, for a time, at a fever heat, and the temperature of 84° may pass unnoticed. It is needless to say that such a strain upon the system is followed by a period of lassitude, and a state of lassitude again may demand a slightly raised temperature. Thus, by degrees, habits of preference for hot rooms may be found. The teacher may be as unconscious of the evil as the scholar; indeed, if fatigued she may require, or if excited may not notice, an unusual heat. The time to correct bad habits in this respect is the beginning of the school year. Every one then comes to school with a system invigorated by some months of exposure to fresh air, and if care is taken, this vigor or power of resisting cold may be retained." To this I would add that a slight modification of the alarm thermometer, which arouses the keeper of a greenhouse by the ringing of a bell when the temperature falls below a certain point, can be easily applied to secure the constant ringing of an alarm whenever the temperature rises above 70°, and that such an instrument would be a very useful reminder and not very costly.

The arrangements for ventilation of school-houses by architects relate, as a rule, mainly to the removal of foul air, no sufficient attention being given to amount and location of fresh-air supply. A common method of construction of late years is to provide an eight or twelve-room school building with two or four aspirating shafts or chimneys connecting with the various rooms and having an aggregate capacity sufficient, with a velocity in these shafts of about eight feet per second, to remove from fifteen to thirty cubic feet of air per head per minute. The air supply in these same buildings is to come from a few 9-inch flues, or, as in the Washington school buildings, through narrow slits placed beneath the window sills. The plan in the Washington buildings is so very bad, and yet was so highly approved by some persons, that it seems worth a little more detailed description. The fresh air is admitted through a perforated iron plate, set in the walls beneath the sills of the four windows in each room. The sum of the area of clear opening in the external plate of each window is from twenty-two to twenty-five square inches, making a total opening for the supply of pure air for the room from eighty-eight to one hundred square inches, or about two-thirds of one square foot, which would not give five cubic feet per minute per pupil. Having passed through the perforated plate above referred to, the air is supposed to pass downward through a narrow slit in the wall, until it reaches the level of the floor, when it turns inward, and then passes up through a steam radiator set against the window breast. Very little air comes through such an arrangement in comparison with what is required, but even this little is carefully shut out in cold weather to prevent draughts and the freezing of the pipes.

This method of heating a school-room by steam pipes placed in the room should never be employed, for it is sure to involve a defective air supply, yet it is one that is peculiarly attractive to those who are not qualified to judge of the relative merits of various methods of heating, since it is comparatively cheap and does give the requisite amount of warmth.

The practical effect of such a system when connected with a large aspirating shaft is that a large part of the air supply in the class-rooms comes from the central hall, as will be seen by testing the direction of the currents at the doors and transoms. This central hall, in turn, derives a large part of its air supply from the basement by means of the stairways. This basement air is liable to be rendered impure by the furnace, and by the water closets, if they are placed in it, which should never be the case.

First of all, then, in planning a school-house, consider the air supply. With regard to the location and direction of the openings in the school-rooms for the admission of fresh air, they should either be situated above the heads of the occupants or be so placed as to give an upward current, for the amount of floor space which can be afforded to each pupil is so small that some of them must be placed in unpleasant proximity to registers located near the floor in the ordinary way. The usual location, and one which gives good results if the fresh-air flues and registers are large enough, is to place them on the outer walls, in which case the window sills are a convenient place for the registers. Mr. W. R. Briggs proposes to introduce the fresh air on the inner wall at a point about two-thirds of the distance from the floor to the ceiling, and has constructed at Bridgeport, Conn., a high school upon this principle.

A description of the heating and ventilation of this building was published in the Third Annual Report of the Connecticut State Board of Health, and a part of this appeared in the *Sanitary Engineer* for December 1, 1881, from which I take the following description and illustrations :

" In the Bridgeport school the coil chambers for the heating of the various rooms have been placed in the main ventilating shafts in the *centre* of the building, and the air conveyed from them through these shafts to the rooms by means of metal flues. The air enters the inner corner of the room, about eight feet from the floor. The outgoing flue has been placed directly under the platform, which is located in the *same corner* as the introduction flue. This platform measures six by twelve feet, and is supplied with casters, so that it can be moved at any time it is necessary to clean under it. Its entire lower edge is kept about four inches from the floor, to give a full circulation of air under it at all points. The action of the incoming air is rapidly upward and outward, stratifying as it goes toward the cooler outer walls, thence flowing down their surfaces to the floor and back across the floor to the outgoing register on the inner corner of the room. By this method all the air entering is made to circulate throughout the room before it reaches the exhaust shaft, and there is a constant movement and mixing of the air in all parts of the room continually going on.

" The inlets are all intended to be large, and the flow of air through them moderate and steady. The air is not intended to be heated to a very high temperature; the large quantity introduced is expected to keep the thermometer at about 68 degrees at the breathing level. The school-rooms contain on an average about 13,000 feet of air, or 260 cubic feet per pupil. It is proposed to supply each pupil with 30 cubic feet of air each minute, or 1,800 cubic feet per hour. Allowing 50 pupils to each room, this will necessitate the introduction of 90,000 cubic feet of air into the room each hour, and will change the air of the room 6.92 times within the hour, or once in about eight minutes. These calculations are based on a difference of 30 degrees in the temperature.

"In the exhaust flues there are placed coils to produce a strong up-current at all times; heat is also obtained from radiation from the introduction and boiler flues, which run through the foul-air shafts.

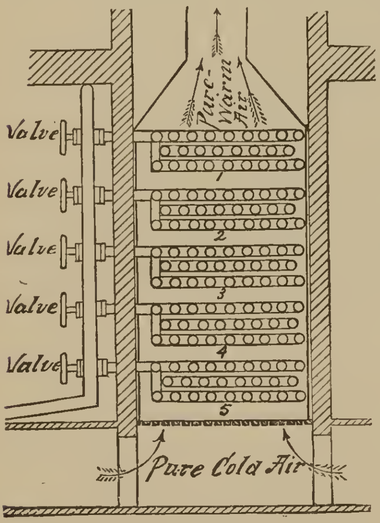


FIGURE 49.—VERTICAL SECTION OF COIL CHAMBER.

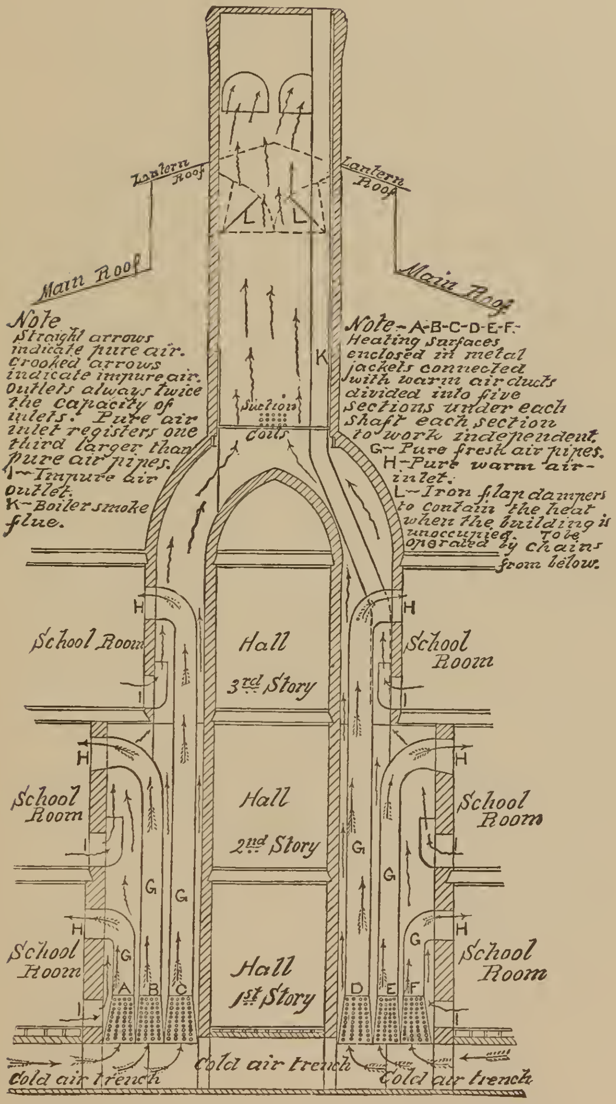
"The heating surface for each room is inclosed in separate cases or jackets of metal, and is then subdivided into five sections, so arranged that any number of sections or the whole may be used at pleasure—that is to say, that any one, two, or more, up to five parts, may be used at discretion. In extreme cold weather the whole five sections are in use; in moderate weather two or three, and when a small amount of heat is required, only one. By this plan the supply of pure air remains always the same, but the degree to which it is heated is changed by the opening or closing of a valve."

This arrangement is shown on the above vertical section of a coil chamber, which represents the actual construction of the coil and chamber, *A*, *B*, *C*, *D*, *E*, *F*, on the section of building.

These large dimensions for the outlet shaft have further support in the mind of the architect in the necessities for summer ventilation.

The results obtained from this arrangement are indicated in the report of an examination made by Dr. Lincoln, which report will be found in the *Sanitary Engineer* for January 11, 1883.

The large opening, shown in the plan at the left of the platform, is into the assembly room through folding doors, and the smaller on the right into the hall. The circles on the plan indicate the position of



Note
Straight arrows indicate pure air. Crooked arrows indicate impure air. Outlets always twice the capacity of inlets. Pure air inlet registers one third larger than pure air pipes.
I~Impure air outlet.
K~Boiler smoke flue.

Note~A-B-C-D-E-F.~Heating Surfaces enclosed in metal jackets connected with warm air ducts divided into five sections under each Shaft each section to work independent.
G~Pure fresh air pipes.
H~Pure warm air-inlet.
L~Iron flap dampers to contain the heat when the building is unoccupied. To be operated by chains from below.

FIGURE 50.—VERTICAL SECTION OF SCHOOL BUILDING.

thermometers, and the numbers beside them are those used in the table below. Where two numbers are attached to one circle, there were two thermometers, one above the other. No. 1 was at the centre of the hot-air register, about eight feet above the floor; Nos. 2 and 3 at a height of twelve feet above the floor (about as high as the instrument could be placed in a vertical position); Nos. 4, 5, 6, 7, 8, 9, 10 and 11 at a height of five feet six inches—level of bulb; and Nos. 12, 13, 14 and 15 at one inch above the floor, No. 15 being in front of the outlet.

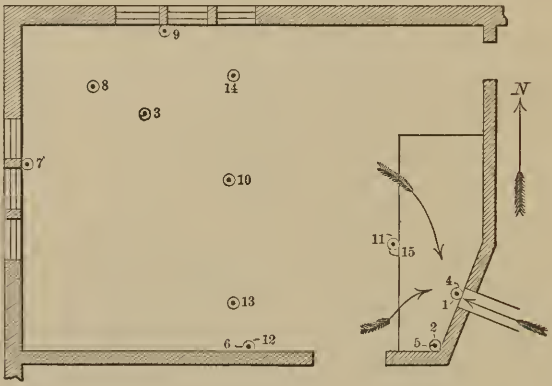


FIGURE 51.

NUMBER OF THERMOMETER ON PLAN.	DECEMBER 22, P. M.					DECEMBER 23, A. M.		
	2h. 40m.	2h. 50m.	3h. 10m.	3h. 25m.	4h. 0m.	9h. 0m.	9h. 40m.	10h. 7m.
1	108°F.	112°	120°	120°	119°	90°	104°	135°
2	74	76	80	81+	84	......	70	80
3	75	78	84	85	87	......	67	79
4	69	70	73	75	76	61	63	68—
5	69	71	74	76	77	61	63	69—
6	69	71	74	75	77	60	62	69
7	71	73	76	78	79	60	63	72
8	68	70	73	75	......	......	......	......
9	70	72	76	77	78	60	62	71
10	69	71	75	76	78	60	63	69
11	70	72	76	77	79	61	63	70
12	67	67	......	70	......	......	......	......
13	66	67	70	......	......	......	60	62
14	65	65	......	69	69+	57	59	60
15	68	69	71	73	......	......	61	64
Outside	......	37	......	36	......	41	......	......

The thermometers used were said to have been carefully selected and compared with each other, and to have had no great variation. The room had been closed (before the afternoon observation) at 12:40. A class of about fifty scholars—the full number—was admitted at three o'clock, and dismissed twenty-five minutes later.

Two measurements were made of the amount of air coming in. The first, at about 2:50, showed nearly 800 cubic feet per minute, and the second, at 3:15, nearly 1,000 cubic feet per minute, or 20 cubic feet per pupil.

In the words of Dr. Lincoln, "abundant proof was given that the current passes very rapidly across the ceiling, quickly down the exposed (outer) walls, then slowly back across the room to the outlet; the range of temperature, regularly falling in about this order, furnishes a proof of this, and further evidence was fully given by the action of the anemometers at the ceiling and at the outer exposed faces of the room.

"In the latter situation, the current was invariably downward, and the elevated temperature at the windows will be noticed.

"To answer a question as to the temperature at the level of the pupils' bodies, a thermometer was placed upon a desk at 14. In the last two trials (right-hand columns) the readings of Nos. 3, 9, the new thermometer, and 14 (respectively placed at the ceiling, at 5½ feet from floor, at the desk level, and at the floor), were 67°, 62°, 60°, 59°; and 79°, 71°, 63° and 60°."

The motive power for ventilation of ordinary medium-sized school buildings can be best secured by an aspirating shaft or chimney, and as a rule two of these, one on either side of the central hall, are to be preferred. The size of these shafts will be determined by the fact that the velocity in them should be from six to eight feet per second. Knowing the total amount of air to be moved per second, the calculation is very simple. If it be decided to use but one large aspirating shaft for the whole building, the best results will be obtained by carrying all the foul-air flues downward, and having them open at the bottom of the shaft.

Whatever be the system of ventilation adopted, it should be supplemented by systematic and thorough aeration of the building by open windows in the intervals of the seasons. No doubt this will chill the rooms in cold weather, and increase the expenditure of fuel, but this is a necessary and legitimate expense.

CHAPTER XI.

VENTILATION OF HOSPITALS—ST. PETERSBURGH HOSPITAL—HOSPITALS FOR CONTAGIOUS DISEASES—THE BARNES HOSPITAL—THE NEW YORK HOSPITAL—THE HOPKINS HOSPITAL.

WE come now to the consideration of a class of buildings in which the subject of ventilation has received more than the average amount of attention on the part of architects—namely, hospitals.

The necessity of providing these buildings with more than the usual means of ventilation has been recognized for a hundred years or more, and in almost every large hospital which has been planned or built during the present century some attempt has been made to meet this demand. Yet, in spite of the experience thus gained, and of some careful studies by physicians, engineers and architects as to the relative merits of various systems, it must be confessed that the results obtained have too often been unsatisfactory.

The bad results of imperfect ventilation, or of an impure air supply, are more strikingly evident in hospitals than in other buildings, owing in part to their continuous occupation, in part to the lowered vitality of their inmates, who are specially susceptible to insanitary influences, and in part to the presence of special causes of disease in the form of germs or miasms. The great difficulty in providing a constant and sufficient supply of pure air to hospital wards, in such a way that at all hours of the day or night, at all seasons, or in all conditions of wind, they shall be free from all odor and comfortable for the patients, is not so much a want of knowledge of the means by which this may be effected as it is the expense which must be incurred, not only in providing the necessary construction and apparatus for heating and ventilation, but also to keep the system in operation after it has been provided. This expense is almost invariably underestimated, and those who have to furnish the funds for the support of the institution are disappointed accordingly, and in attempting to reduce the cost are too apt to reduce the ventilation also.

The hospitals for which an architect is liable to be called on to prepare plans may be roughly divided into four classes. The first are those intended for the reception of contagious diseases, the so-called pest-houses. These are usually cheap temporary structures, hastily erected to meet an emergency, and the architect is rarely consulted with regard to them. It would be much better if he were, for such hospitals should be considered as an indispensable part of the municipal machinery of every city of 10,000 inhabitants and upward; they should be carefully constructed while the emergency is yet afar off, and while they should be simple and cheap, they should have a neat and attractive appearance, instead of looking, as they usually do, like an enlarged dog kennel. Their ugly, box-like appearance can be done away with by a simple, broken, cottage-like outline, without much additional expense, and they will then be considered as worth taking care of. They will be one-story wooden buildings, with wards containing about six beds, heated by a stove in the centre. Through or around this stove the greater part of the fresh air should be introduced in cold weather, while the foul air should be removed by a shaft reaching nearly to the floor near the stove, and containing the stove-pipe in its upper part. The amount of air supply should not be less than one cubic foot per head per second. Upon a larger scale this kind of building is known as a barrack hospital, and excellent results have been obtained from it. To illustrate its possibilities I give figures showing plan and cross section of one of the barracks of the Roschdestwensky City Hospital, in St. Petersburgh.

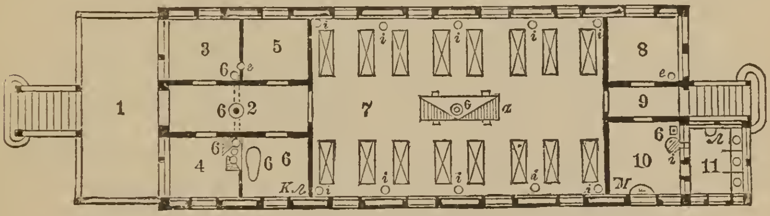


FIGURE 52.—FLOOR PLAN OF ST. PETERSBURGH CITY HOSPITAL.

1.—Porch.
2.—Hall.
3.—Nurses' Room.
4.—Ward Kitchen.
5.—Room for two patients.
6.—Bath.
7.—Ward.
8.—Room for two patients.
9.—Hall.
10.—Wash-room.
11.—Water Closet.

This hospital has three of these barracks, constructed in 1871–72, and they have proved to be a great success, being comfortably warm in the extreme cold of the Russian winter, and giving excellent results in cases of typhus and also in surgical cases.

The walls of this barrack are triple, inclosing two air spaces. The arrangement of the ward heating and ventilation is sufficiently shown in the figures. The great central German porcelain stove is fourteen feet long, four feet eight inches wide, and six feet high. This so-called stove is rather a furnace, fired from below, and has through it eight openings for the admission of fresh warm air into the ward. The foul-air flues open into the central smoke flue, as shown in the cross section. Besides this central stove, there are three others, and the whole furnish about 103,000 cubic feet of fresh air per hour. When the external temperature is not below the freezing point these stoves are fired but once a day. When between zero and 32° F., they are fired twice a day, and when below zero, three, and in extreme cold, four times a day. When I was in this ward in August, 1881, it was quite free from unpleasant odor, although it was filled with fever cases; the day was cold and raw, but the temperature of the ward was all that could be desired. It is an interesting hospital, as proving that even in the coldest climates such wards can be made perfectly comfortable and at the same time be kept well ventilated.

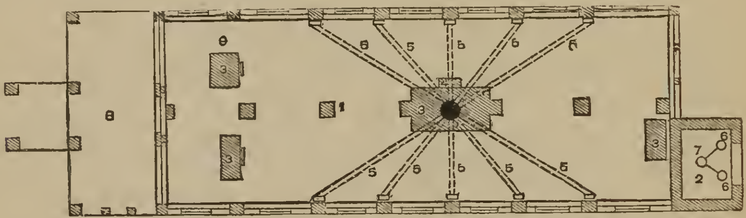


FIGURE 53.—CELLAR PLAN OF ST. PETERSBURGH CITY HOSPITAL.

1.—Cellar.
2.—Soil Pipes.
3.—Foundation of Stone.
5.—Foul-Air Tubes beneath the floor.
6, 7.—Vessels for Excreta.

Allusion has been made above to small hospitals for contagious diseases as being usually simple and cheap. Within the last year, however, it has been suggested that more elaborate arrangements may be necessary in the case of those small-pox hospitals which are to be located in large cities with comparatively thickly settled suburbs. In the report presented by the Royal Commission of Great Britain appointed to inquire respecting small-pox and fever hospitals, the conclusion is arrived at, expressed, however, with some doubt and hesitation, that small-pox hospitals may diffuse infection around them through the atmosphere independent of any conveyance of the contagion by persons or things going from the hospital, or of the transportation of patients to it. This conclusion is based mainly on the investigation made by Mr. Power as to the diffusion of small-pox from Fulham Hospital, and as the result the commission state that in the present state of our knowledge it is essential that in the construction and management of small-pox hospitals both atmospheric dissemination and personal communication should be, with the utmost care, guarded against. To prevent the atmospheric dissemination the commission recommend that not more than 30 or 40 small-pox patients should be placed together in one locality, and that separate small-pox buildings should be so constructed as to reduce within the smallest limits the chance of spreading infection. They say: "We fully believe that contrivances for this purpose might be devised, and we again call special attention to the evidence on this point which has been furnished to us by Dr. Burdon Sanderson."

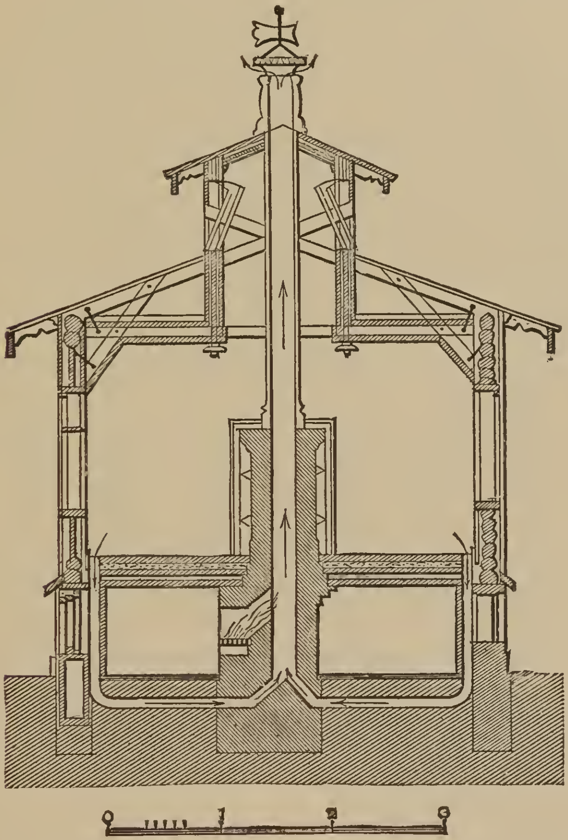


FIGURE 54.—CROSS SECTION, ST. PETERSBURGH CITY HOSPITAL.

Turning now to the evidence of Dr. Burdon Sanderson, who is one of the most distinguished scientific men in England, and whose advice in such a matter is entitled to the greatest respect, even if it were not indorsed as it is by the commission, we find that he proposes to so construct the small-pox ward that all the air in it which has come in contact with the patients can be subjected to a high temperature to destroy its dangerous properties. He says: "As the outlets of air are the sources of danger, and not the inlets, it is preferable that the air should be drawn out of the hospital, and not driven into it, and, consequently, we should choose a mode of ventilation accordingly, and that being adopted, the beds for the patients should be placed as near the outlets for air as possible; and further, the outlets themselves should be as near together as possible. The communication between the outlets and the source of motion, whatever its nature might be, should be as direct and ample as possible. Considering all these purposes, it is desirable that each ward should be in the form of a ring, with the chamber from which the air is directly extracted in the centre of the ring, the annular being the simplest form that can be given to it; that is to say, the one that makes it possible to make the opening for extraction of air communicate more directly than any other with the space in which each bed is contained. Then for a ward of 12 beds, having a capacity of about 1,200 cubic feet per bed, the removal of air should be about 120,000 cubic feet per hour, and, consequently, the removal of air per patient 10,000 cubic feet per hour. * * *

"The beds would be arranged as near as possible to and immediately below each extracting opening, and would be placed against the internal wall, and each bed would be placed between two of the septa or screens which pass to a certain distance out from the internal wall into the annular space, so that the head of each bed would be included in the space between each two neighboring septa. The space within the ring communicates with the annular space which answers the purpose of the ward, by extracting openings, and also with an extractor, preferably a fan. An extracting shaft might, of course, be substituted for the fan; but I think a fan preferable, on the ground that its action is more independent of temperature and wind, and, therefore, more constant, and that it is more economical. The fan would collect the air from the ward and at once discharge it into a chamber, where it could be subjected to a higher temperature, so as to destroy all organic matter it might contain."

The windows are not to open. Twenty-four openings for fresh air are to be made in the external wall, each having two square feet of area. The movement of air through the outlet openings is intended to be at the rate of one mile per hour, allowing 10,000 cubic feet of air for each patient, and to secure this slow movement and thus prevent draughts, the outlet openings are also to be two feet square. The method of warming proposed is to carry around hot-water pipes in front of the inlet openings. From the fan the air is to pass to a gas furnace, probably in the roof of the house.

From this description and the accompanying plans, of which copies are appended, it is evident that while it is theoretically possible to thus disinfect all the air passing through a small-pox ward, it would be at a relatively great expense. The circular ward is used in the new City Hospital at Antwerp, and the same principle is employed in the Octagon

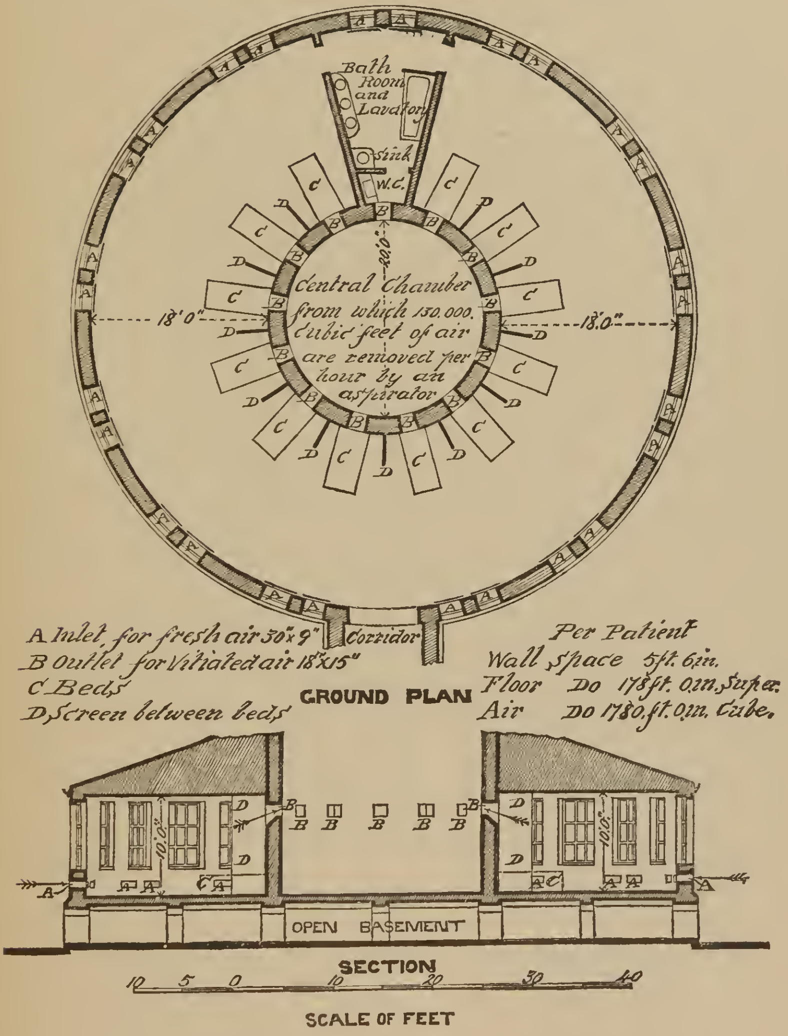


FIGURE 55.

Ward of the Johns Hopkins Hospital, at Baltimore; but in both these the beds are arranged against the outer wall, having the heads toward the windows, which is a much more convenient way of arranging them than in the plan above proposed, both because it allows more space about each bed and because it does not put the patients facing the light, which would be extremely unpleasant in the acute stage of small-pox.

A second objection is that the central shaft is unnecessarily large, as are also the inlets into it. It is not desirable to reduce the velocity of the air at the outlets or in foul-air ducts below four or five feet per second, because at very low velocities a very slight thing will disturb the currents. The velocity at the outlet has comparatively little to do with the production of draughts. There seems to be no necessity whatever for the use of an aspirating fan in the plan proposed. If the air is to be heated to a temperature of 250° F. and upward, which is necessary to secure its disinfection, this heat will in itself furnish all the aspirating power required. The use of gas to produce the heat required for such large quantities of air would also be unnecessarily expensive; a coal furnace would do the same work at half the cost.

In the plan proposed, in cold weather, a large amount of the incoming fresh air, and the heat employed in warming it, would be wasted, since it would rise rapidly from the point of entrance, taking almost a direct line to the point of exit, and passing above the beds, the occupants of which thus get no benefit from the main stream of fresh air, but must rely on what comes to them from a sort of eddy and from diffusion. It would have been much better to introduce a large part of the air through a grating beneath and between the beds, in which case the patients could be kept bathed in a steadily ascending stream of air, moving at the rate of, say, four inches per second; and this could be effected with less than half the amount of air and expenditure of fuel required in the proposed plan. In this country, however, where provision must be made for temperatures at least as low as zero F., it is desirable, on the score of economy, and to secure sufficient warmth, to arrange the flues so that the foul air shall be taken from points in or near the floor. It should be remembered that in a hospital of this kind, where special arrangements are to be made to secure a steady, uninterrupted stream of air through the ward, the allowance of floor space and cubic air space per second becomes of secondary importance, so far as ventilation is concerned, and may be fixed mainly by considerations of convenience of administration. This ward might be made ten feet less in diameter and the central shaft reduced to four feet in diameter with good effect.

These suggestions are made, not for the purpose of fault-finding, but because everything which comes from such distinguished authority should be made as perfect as possible.

It seems probable, however, that the neighborhood would be more certainly and economically protected by the continuous enforcement of vaccination than it would be by any particular form of hospital.

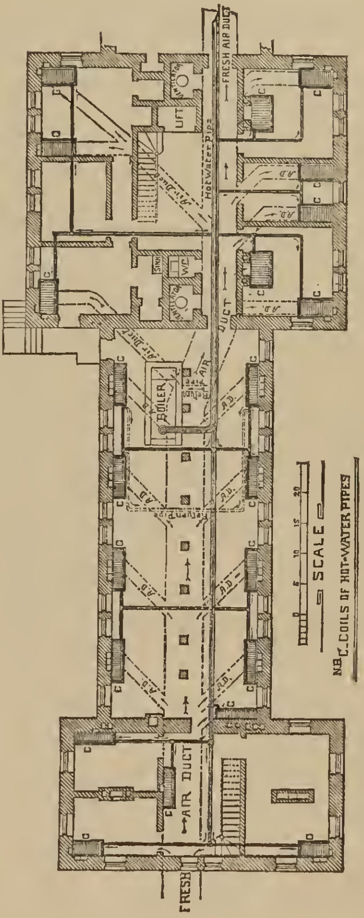


FIGURE 56.—BARNES HOSPITAL. PLAN OF BASEMENT, WITH FRESH-AIR DUCTS AND HEATING APPARATUS.

Of all small hospitals in this country with which I am acquainted, the one in which the heating and ventilation has been most thoroughly proved to be satisfactory is the Barnes Hospital, at the Old Soldiers' Home, near Washington, the general arrangement of which is shown in the accompanying illustrations.

This hospital is built of brick, and consists of a central administration building measuring 52 x 55 feet, two pavilion wings each 64 x 29 feet, and two end towers each 24 x 46 feet. The central building has a basement, three stories and a mansard roof, the rest of the structure two stories, with basement and mansard.

The total amount of cubic space to be heated is about 310,000 cubic feet. The basement is occupied by the heating apparatus, which is hot water, and consists of two tubular boilers, each nine feet long and 42 inches in diameter, with mains, pipes and coils. The heating coils are of cast-iron pipe, three inches in diameter, and are placed in fresh-air chambers in the basement, as shown in the plan. At the point of entrance of the supply pipe to each coil is a valve, by which the flow of hot water may be diminished to any degree, and the temperature of the coil regulated accordingly.

The fresh-air flues are of terra-cotta pipe, built into the walls and opening into the space above the heating coils.

The apparatus has maintained a uniform temperature of about 70° F. in the coldest weather, and the temperature can be varied at the different registers to suit the feelings of patients near them.

From May to September the doors and windows are usually open, and, for the most part, the natural ventilation thus secured is sufficient, but on some hot, close days and nights in this period, when there is no wind, it becomes desirable to use special means to secure ventilation, and this is done by either aspiration or the use of the fan, or by a combination of the two.

When the natural ventilation by open windows is insufficient or impracticable, fresh air is supplied by a shaft eight feet in diameter and thirty-eight feet high, placed seventy-four feet west of the building. This shaft is connected with a brick air duct, 286 feet long, which passes beneath the basement through its entire length, and gives off branches leading to the air chambers containing the heating coils.

At the point of junction of the vertical shaft with the fresh-air duct is located the fan, which is eight feet in diameter and has twenty-four blades, each twelve inches wide.

The motive power for this fan is furnished by a six-horse power engine, and the amount of coal required to run it is about 140 pounds for twenty-four hours. The fan is usually run at sixty revolutions per minute, giving a velocity in the air duct of from four to six hundred feet per minute, the cross section of the duct at its throat being forty feet square. The removal of foul air by aspiration is effected by two chimneys in the administration building. Each chimney measures four feet four inches by five feet eight inches, and is ninety-six feet high.

A boiler-iron flue, two feet in diameter, is placed in the centre of each chimney, extending from the basement to a height of three feet above the chimney cap ; into these flues pass all the products of combustion from the hot-water and steam-boiler furnaces, as well as those from the kitchen range. Each flue has a basket grate at its base, in which a fire can be built when the furnaces are not acting.

Into the chimney shafts outside these flues empty the foul-air ducts from the wards. These ducts are three feet three inches wide, one foot deep and fifty feet long, and are placed above and below the centre of each ward with which they communicate by accurately closing registers placed in the centre of the floor and ceiling. These foul-air boxes are lined with tin and are cleaned daily.

Each ward contains 12 beds, is 50 x 24 x 15 feet, and has five foul-air registers along the centre line of the floor and five in the ceiling.

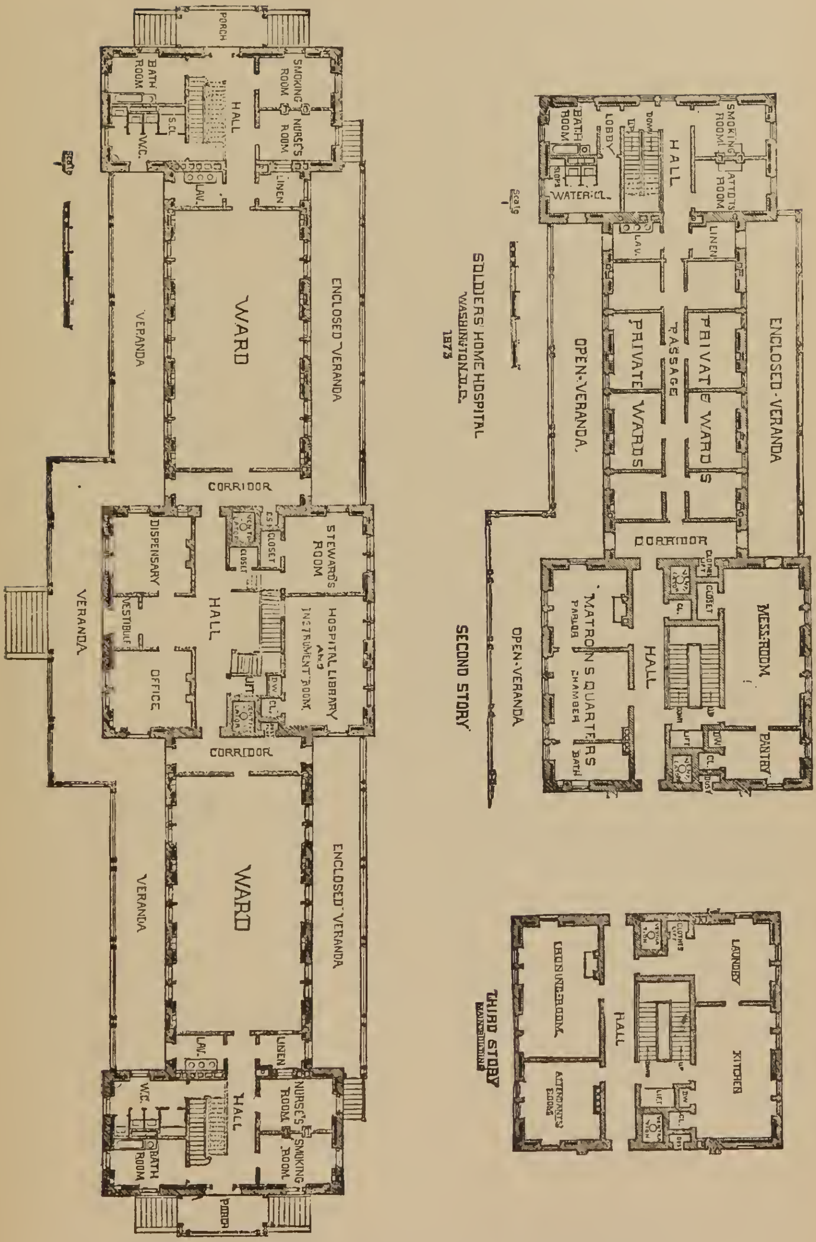


Figure 57.—HOSPITAL AT SOLDIERS' HOME, WASHINGTON, D. C.

Each of the upper registers has a clear area of 1.33 square feet of opening, and each lower register 1.5 square feet of clear opening. Each lower ward has sixteen fresh-air inlets, eight being ten inches above the floor and eight ten inches below the ceiling; in the upper wards the upper registers are omitted. Each fresh-air register has a clear area of one square foot.

The double set of inlets in the lower wards was arranged for experimental purposes to test the value of General Morin's theory that the warm air should be introduced at the ceiling. It was found that when this was done there was a difference of 10° in the temperature between the floor and the ceiling, and that the patients complained of cold feet and discomfort. It is also evident that when the warm air is introduced near the ceiling it is impossible to vary the temperature at different beds, a thing which it is often desirable to accomplish in a hospital.

The mean velocity of the upward current of air in the aspirating chimneys is about 180 feet per minute. With good fires in the grates at the base of the flues the highest recorded velocity was 700 feet per minute.

Each chimney under ordinary circumstances removes from the two wards connected with it about 36 cubic feet of air per second, or one and one-half cubic feet per second per man.

This supply can be at any time doubled by the use of the fan. When fires are used at the base of the chimneys to accelerate the aspiration the consumption of coal is about 30 pounds of anthracite per hour per grate.

The following data are taken from a report which was printed for the use of the trustees of the Johns Hopkins Hospital, in Baltimore, but which was never published, and is now rare. The observations were made and reported by Surgeon D. L. Huntington, U. S. Army, to whose superintendence much of the success of the system was due.

The following are instances of experimental use of the fan:

June 7. External air 75° F.; 5 P. M., temperature of air-supply duct 68° F., 20 lbs. steam; 120 revolutions of fan per minute.

Velocity of air at throat of duct (40 square feet area) 1,350 feet per minute at the nearest inlet into ward:

1st story (100 feet from throat)................450 feet per minute.
2d “ 118 “ “ ....420 “ “
3d “ 132 “ “ ....340 “ “

At most remote inlet into ward:

1st story (298 feet from throat)................410 feet per minute.
2d “ 315 “ “ ....220 “ “
3d “ 331 “ “ ....139 “ “

On this trial all registers were open, also all doors, windows, and ventilating outlets, the resistance to the fan being reduced to a minimum.

Nov. 1. Temperature of external air 45° F., of duct 46° F., 20 lbs. steam; 120 revolutions of fan per minute.

Velocity of air at throat of duct 1,320 feet per minute at the nearest inlet to ward:

1st story (same distance as above)	530	feet	per minute.
2d " " " "	360	"	"
3d " " " "	269	"	"

At most remote inlet into ward:

1st story	750	feet	per minute.
2d "	500	"	"
3d "	298	"	"

In this experiment all windows and doors were closed, the ventilating registers and outlets being open.

It will be seen that in the first experiment the pressure of the air as indicated by the velocity was greatest at the inlets nearest the fan, while the reverse was the case in the last trial. The direction and force of the prevailing wind also has a very considerable influence on the movement of air through the fan and in the duct. Dr. Huntington remarks that "a long series of experiments at different seasons of the year have all yielded harmonious results. Beyond a velocity of from 800 to 900 feet per minute in the main duct, the effective force of the air is much impaired, and the result usually seen at the inlets nearest the fan is a lessened current. The general rule in working the fan is to use 15 lbs. of steam and not over 60 revolutions per minute, equal to from 400 to 600 feet per minute in the duct; this gives all the air needed for the building, and brings the consumption of fuel to its lowest point. With this velocity air enters the wards at the rate of from two to four feet per second."

A specially interesting experiment was made in one of the wards on the night of Nov. 28, which is thus reported by Dr. W. M. Mew, who made the air analyses. Ward B (for 12 beds) contained 11 patients; the ordinary ventilation was going on.

Ward D had 12 beds; all occupied. All the outlets had been closed for 35 minutes before the first experiment, in order to make the air thoroughly impure, which was accomplished, as is shown by the high percentage of carbonic acid obtained.

The second experiment was made in the same ward just ten minutes later, during which time the outlet and inlet flues were open and the fan making sixty revolutions per minute.

It will be seen from the following table that the use of the fan in this way for ten minutes made the very impure air of the ward nearly as pure as the outer air :

AIR, WHENCE TAKEN.	TEMPERATURE.		Difference.	Relative Humidity.	Vols. of CO_2 in 10,000.
	Dry bulb.	Wet bulb.			
Outside	49° F.	45° F.	4	73	3.05
Ward B	68° F.	57° F.	11	40	6.35
Ward D, 1st experiment	77° F.	61° F.	16	38	11.23
Ward D, 2d "	80° F.	66° F.	14	..	3.75

At the time of this observation there was very little wind, the barometer was 29.72, the temperature in the aspirating chimneys was 79° F., and the average velocity of the upward current in them was 120 feet per minute.

The amount of anthracite coal used for heating the hospital with the external temperature at 39° F. averaged 1,184 lbs. for 24 hours.

The table on the following page shows the observations made of the heating and ventilation of this hospital during the first week in December, 1877. All velocities are stated in feet per minute, and each reported observation is the mean of three trials.

December.	1	2	3	4	5	6	7
Barometer	29.804	30.268	30.230	30.062	29.615	29.771	30.125
External Temperature	38°	31°	33.5	37	53	40	36.5
Wind, direction and force	N. W.²	N.²	N. W. S. E. 1	S²	S. W. 0–4	N. W. 4–6	S. W. 1–4
Relative humidity of external air	87	92	66	78	78	58	57
Aspirating chimneys. East. Temperature of chimney	69	75	76	75	75	75	75.5
Aspirating chimneys. East. Velocity of air current	186	280	375	346	326	400	444
Aspirating chimneys. West. Temperature of chimney	70	73	74	73	74	76	73
Aspirating chimneys. West. Velocity of air current	126	150	280	293	150	353	264
Outflow from foul-air registers, east wing	200	150	120	139	120	190	240
" " " west wing	210	153	146	113	106	180	213
Inflow of fresh air, east wing	150	205	173	190	306	166	189
" " " west wing	110	166	153	166	340	160	220
Gauge of heating furnaces	135	142	142	140	135	140	143
Temperature of hot air at registers of wards, east wing	97	98	102	102	104	103	96
" " " " west wing	100	105	106	93	100	108	102
Average temperature of wards at floor, east wing	71	73	74	71	72	71	72
" " " centre, east wing	73	75	74	73	74	75	76
" " " ceiling, east wing	73	76	76	75	75	73	73
" " " floor, west wing	72	70	72	74	74	72	74
" " " centre, west wing	72	72	71	69	72	72	74
" " " ceiling, west wing	74	73	73	70	74	74	77
Temperature of distal foul-air boxes, east wing	72	70	75	73	77	76	73
" " " west wing	73	71	74	72	75	72	74
Average relative humidity of house	59	45	44	54	56	52	47

REMARKS:—December 1. Clear and cool; both furnaces going. Fan not running.

December 2. Calm and cool; both furnaces going. Fan not running.

December 3. Cloudy and still; both furnaces going. Fan running moderately.

REMARKS:—December 4. Cloudy with rain; fan running. Both furnaces going.

December 5. Warm and muggy; W. furnace discontinued. Fan not running.

December 6. Fan not running. W. furnace discontinued.

December 7. Clear and cool; fan not running. W. furnace discontinued.

While the ventilation and heating of the Barnes Hospital have proved to be very satisfactory, as is shown not only by continued and carefully applied tests, but also by the fact that while for the last four years this hospital has been constantly overcrowded, in the sense that it has contained from 25 to 40 per cent. more patients than it was intended for, no evil results have thus far been produced, and the air in the hospital is, as shown by very recent examination, quite free from unpleasant odor; there are, nevertheless, some points in regard to which its arrangements for ventilation might be improved.

In the first place, there are no means by which the temperature of the fresh air issuing from any given register can be rapidly changed without interfering with the amount of air introduced. I say "rapidly changed," because the change can be effected by varying the amount of hot water allowed to circulate through the coil, by means of the valves placed in the supply pipe for each coil; but it requires nearly an hour for the coil to cool down to the extent that it is sometimes desirable should occur in five minutes. The means by which this rapid change can be effected will be described presently.

In the second place, the proportions of the air ducts, fan and chimneys are not quite such as to secure the best results obtainable with a given expenditure of force. The amount of air delivered at some registers is greater than that which comes from others, and the same is true as regards foul-air exhausts, so that in order to secure sufficient supply and exhaust at all points we must have more than is necessary at some points. It is very true that this excess is useful, and that as regards hospital ventilation, "nothing less than too much is enough."

A third objection is the position of the foul-air registers in the floor along the centre of the ward. The tendency of patients to spit down these registers or to throw things into them is very great, and while no evil results have followed in a hospital which is under military discipline, and where the foul-air boxes are cleaned every day, it is better to transfer these registers to a point beneath the beds, where they are out of the way and equally efficacious.

The placing of the kitchen in the third story of the hospital was a decided success in more ways than one. The odors from cooking are almost entirely excluded from the building, although sometimes the lift which passes from the kitchen down to the dining-room acts as a sort of air-pump, and draws or forces some of the air from the kitchen down to the second floor.

This principle of placing the kitchen on the upper floor was adopted in the new New York Hospital, the plans for which, prepared by the architect, Mr. George B. Post, were adopted in 1875.

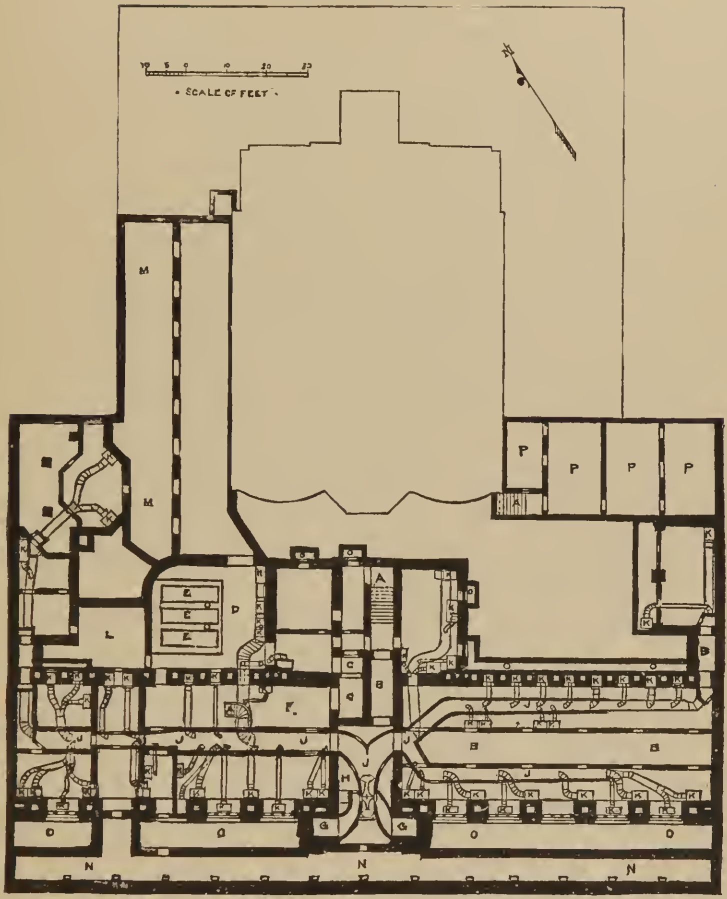


FIGURE 58.—NEW YORK HOSPITAL BUILDINGS.—PLAN OF CELLAR.

A.—Stairs.
B.—Corridor.
C.—Elevator.
D.—Boiler Room.
E.—Boiler.
F.—Engine Room.
G.—Fresh-Air Duct.
H.—Engine.

I.—Fan Blower.
J.—Cold-Air Duct.
K.—Steam Coils.
L.—Ash Vaults.
M.—Coal Vaults.
N.—Vaults.
O.—Area.
P.—Vegetable Vaults, etc.

Q—Ice House.

This hospital is located near the centre of New York City, and is an illustration of an attempt to make up in height for deficiency in ground area.

The general arrangement is shown in the accompanying plans, which are copied from those prepared by the architect to illustrate his description of the building, which is of brick, and contains 163 beds. In the wards there is one window to each bed, each external pier of the building being a flue, which is lined with hollow bricks to prevent, as far as possible, loss of heat by radiation. Through the centre of these flues run cast-iron pipes, intended to be fitted so as to be air-tight, and through which fresh air is taken to the building, being forced in by a fan.

The spaces outside these fresh-air pipes are the foul-air flues. These terminate above in pipes leading to an exhaust fan, which is located in the top of the centre building.

The heating is by steam, the coils being arranged at the bottom of the fresh-air pipes in such a way that by a valve the cool air from the propelling fan can be sent either through or around the heating coil. The fresh air is admitted to the wards through slits in the window sills, forming a jet directed upward on the principle of Tobin's tubes. A similar arrangement exists in the pavilion of the London Hospital, erected in 1875–6.

The openings for the exit of foul air from the wards are in part placed in the walls of the piers and in part beneath the beds.

No effort or cost was spared in the construction of this building to overcome the difficulties connected with the arrangement of heating and ventilation of a building of so many stories, all of which through the staircase halls and elevator shafts are practically in free communication with each other, and a fair amount of success has been attained. I do not know of any published observations showing what the actual operation of the apparatus is, but I have visited the hospital several times, and have twice tested the currents with the anemometer. These testings made the average air supply to be about 2,400 cubic feet per bed per hour—an insufficient amount, if all the beds were full, which, however, was not the case.

The principle of placing fresh-air pipes inside of the foul-air ducts is one that cannot be approved of for hospital ventilation, for although the fresh-air pipes are of iron, and may have been tightly fitted, it is a mere question of time when some communication will be established between the inner and outer surfaces of these pipes, either by rusting or by alternate expansions and contractions, and then the foul air may be carried back into the wards. The iron pipes are not readily accessible,

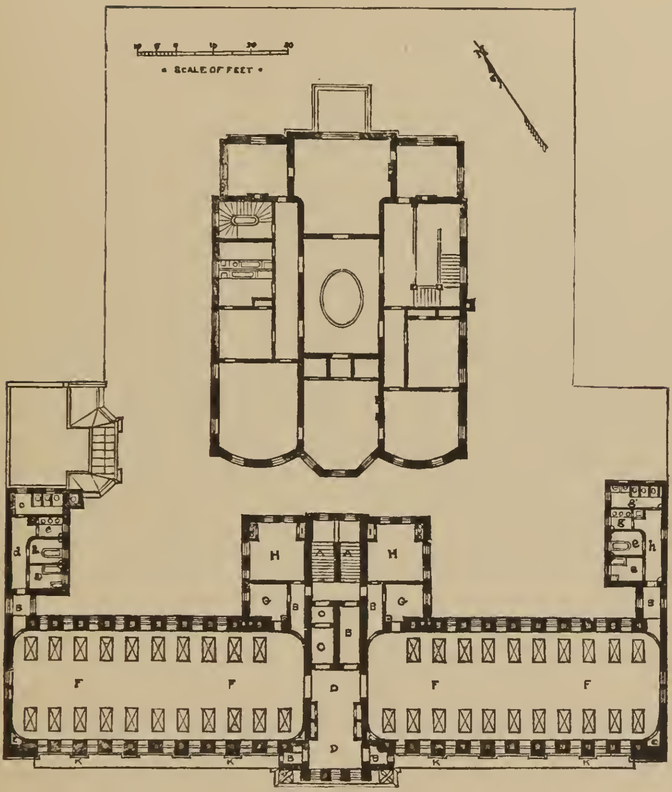


FIGURE 59.—NEW YORK HOSPITAL BUILDINGS.—PLAN OF SECOND, THIRD AND FOURTH STORIES.

MAIN BUILDING.

A.—Stairs.
B.—Corridor.
C.—Elevator.
D.—Hall.
E.—Closet.
F.—Ward.
G.—Nurses' Room.
H.—Dining-Room.
I.—Dumb Waiter.
J.—Ventilating Duct.
K.—Balcony.

WEST WING.

a.—Bath Room.
b.—Sink.
c.—Toilet Room.
d.—Corridor.

EAST WING.

e.—Bath Room.
f.—Sink.
g.—Toilet Room.
h.—Corridor.

ADMINISTRATION BUILDING.

Library and Museum Floor.

inclosed as they are in the brick walls, and there is no ready means of determining their condition. On one occasion, when I visited the hospital, the fumes of burning sulphur, which was being used to disinfect a room at some little distance, entered the room in which I was. Precisely how this was effected could not then be ascertained, but it indicated that the system was not working satisfactorily.

The principle of having two fans, one for propulsion and the other for exhaust, is not peculiar to this hospital ; it was tried for several years in the hall of the House of Representatives, at Washington, but the results were not satisfactory, and the plan is not one to be recommended. A single powerful exhaust is the system best calculated to overcome the peculiar difficulties met with in attempting to secure a satisfactory distribution of air in a lofty hospital of many stories.

But while the resources of modern engineering are no doubt competent to secure satisfactory ventilation in a hospital ten stories high, if necessary, they can only do this at a comparatively great cost, and it is therefore now generally admitted that it is best to put hospitals where they can have plenty of room and fresh air, without being compelled to go upward for them.

Another method of arranging the ventilating shaft and foul-air ducts has been employed in the common wards of the Johns Hopkins Hospital, Baltimore. These wards are contained in pavilions of one story and a basement. The basement is devoted entirely to heating and ventilation purposes, forming practically a large clean-air chamber containing the hot-water coils for heating, and from which the air supply for these coils can be taken when desired. Usually, however, the supply will be taken directly from the external air. The accompanying figure shows the plan of the ward, and the general arrangement of the foul-air ducts. Each of these wards is practically a separate small hospital, and it is impossible to pass from one ward to another, or from the corridor which connects the basements to the wards, without going into the open air.

Each of the wards has a separate aspirating chimney, located as shown in the plan, in an octagonal hall or vestibule on the connecting corridor. Into this chimney empties a foul-air duct, which runs longitudinally beneath the centre of the floor of the ward, and which receives the air from lateral ducts opening beneath the foot of each bed. The main foul-air trunk is made of wood, lined with galvanized iron, and the lateral pipes are of galvanized iron, and cylindrical in shape.

A similar duct is placed above the ceiling, and communicates with the ward by five openings in the ceiling, in the longitudinal central axis. Just above where this upper duct enters the chimney, there is

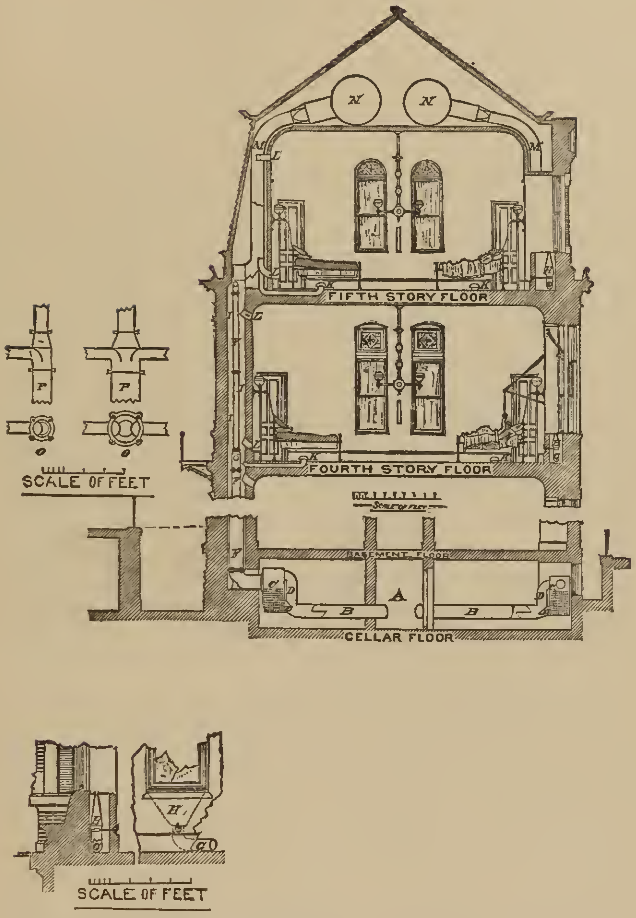


FIGURE 60.—NEW YORK HOSPITAL BUILDINGS.—DIAGRAM OF VENTILATION AND HEATING.

A.—Main Fresh-air Shaft from Blower.
B.—Connection to Steam Coil.
C.—Steam Coil.
D.—Cold-air Passage around Steam Coil.
E.—Valve to regulate Temperature by passing any required portion of the air around the Steam Coils.
F.—Hot-air pipes.
G.—Connections to Registers.
H.—Register Box and Opening.
I.—Ventilating Flue containing Hot-air Pipes.
K.—Main Orifices for Ventilation.
L.—Orifices for Ventilation for occasional use.
M.—Ventilating Pipes.
N.—Trunk Ventilating Pipes leading to Exhaust Blower.
O.—Plans of Connnections of Hot-air Pipes.
P.—Sections through Connections of Hot-air Pipes.

placed in the shaft a coil to be heated by high-pressure steam when it is necessary to quicken the aspirating movement.

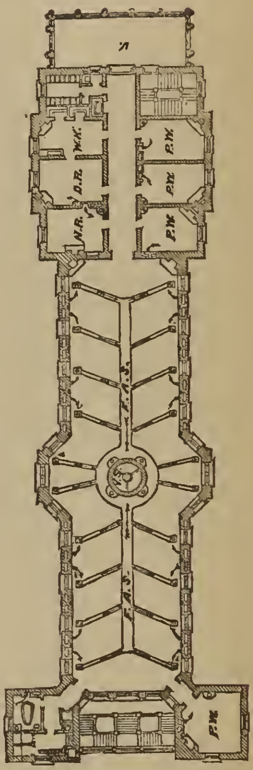


Figure 61.—SECOND STORY PLAN OF "ONE" MEDICAL PAVILION OF THE COOK COUNTY HOSPITAL, IN CHICAGO, ILL.

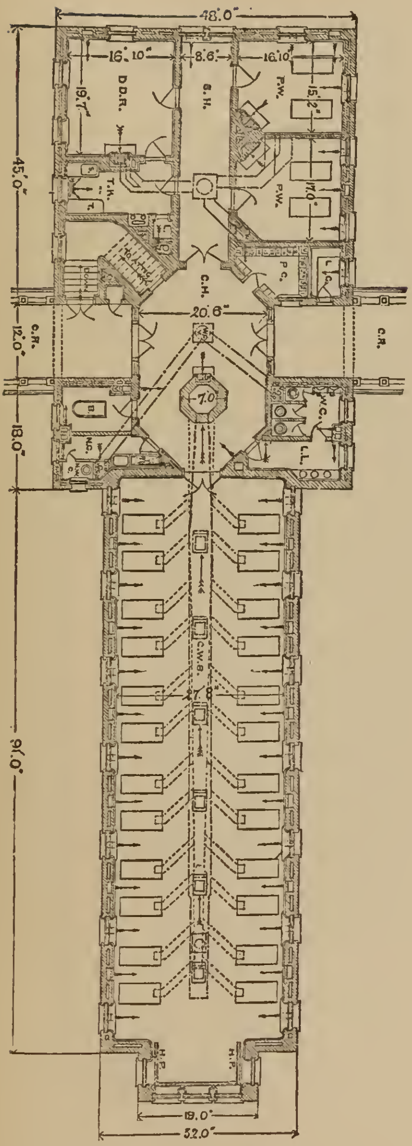
C. S.—Clothes Shoot.
V.—Veranda.
F. A. S.—Foul-Air Shaft.
P. W.—Private Ward.
V. W.—Ventilating Shaft.
N. R.—Nurses' Room.
D. R.—Dining-Room.
W. K.—Ward Kitchen.

It will be seen, therefore, that the foul air can be taken either at the level of the floor beneath the beds or from the centre of the ceiling; the first method will probably be employed in winter and the second in summer.

The main central aspirating chimney is devoted to the ventilation of the ward only. All the service rooms have separate and independent exit shafts of galvanized iron passing up through the roof, and capped with a modification of the Emerson Ventilator.

Each ward will have a small propelling fan placed in the basement, the ducts from which open beneath the heating coils, the object being to secure a thorough air flush of the ward two or three times a day, and also to supplement the aspirating shaft on the very few days of the year when such aid may be useful.

Excluding hospitals for the insane, the New York Hospital is the only building of this kind in the world in which fans are entirely relied on for production of ventilation. In most of the large and costly hospitals of recent construction in this country, the power relied on to produce movement of air is an aspirating chimney or shaft. This may be either one large shaft connected with the several wards, and heated by the smoke-pipe of the boilers, as is done in the Cincinnati and the Roosevelt Hospitals, or it may be by a shaft for each pavilion, which is the more usual plan. One arrangement of this last plan has been already shown in the description of the Barnes Hospital. Another arrangement is that adopted in the Cook County Hospital, at Chicago, in which the pavilions are three stories high, and the aspirating shaft is placed in the centre of the pavilion, as shown in the cut. This building is heated by steam by the usual indirect-radiation method, the fresh air being delivered



L.—Lift.
L. V.—Lift Vent.
H. P.—Heating Pipes.
H.—Heat.
N. W. C.—Nurses' Water Closet.
W. C. V.—Water Closet Vent.
. . . . . .—These lines indicate Ventilating Pipes under Floor.
- - - —These lines indicate Ventilating Pipes in Attic.
S.—Steam.
P. W.—Private Ward.
P. C.—Patients' Clothing.
L. C.—Linen Closet.
C. R.—Corridor Roof.
S. H.—Service Hall.
C. H.—Central Hall.
D. D. R.—Dining and Day Room.
T. K.—Tea Kitchen.
N. C.—Nurses' Closet.
W. C.—Water Closet.
C. W. B.—Common Ward for Beds.
T.—Table.
S.—Sink.
L. L.—Lavatory Lobby.
U.—Urinals.
B.—Bath.

FIGURE 62.—JOHNS HOPKINS HOSPITAL, BALTIMORE, MD.—COMMON WARD, FIRST STORY PLAN.

by flues and registers in the outer walls. The foul air is supposed to be removed by ducts opening into the ward in the floor between the beds, and passing thence to the central aspirating shaft. I am not aware that any scientific observations have been made as to the effects of this system, but I believe there has been trouble with the heating, probably owing to too small an amount of heating surface, want of means of tempering the air, etc.

CHAPTER XII.

FORCED VENTILATION—ASPIRATING SHAFTS—GAS JETS—STEAM HEAT FOR ASPIRATION—PROF. TROWBRIDGE'S FORMULÆ—APPLICATION IN THE LIBRARY BUILDING OF COLUMBIA COLLEGE—VENTILATING FANS —MIXING VALVES.

In ordinary dwellings, and for almost all buildings where but few persons are gathered in each room, it is unnecessary to provide special apparatus for forcing or increasing the movement of the air. During warm weather, open windows and doors afford, in most cases, sufficient change of air, and in cold weather the expansion of the air by the action of the heating apparatus and the increase of temperature due to the bodily warmth of the tenants, to lights, etc., furnish sufficient motive power if the flues and registers are of proper size and rightly placed. But in this country and climate there are a certain number of days in the spring and fall when it is too warm to permit of the use of heating apparatus and when there is no wind. In halls of assembly of all kinds, and especially in theatres, in hospitals, in certain manufactories where noxious or offensive gases or dusts are produced, and in mines, tunnels, etc., it is often very desirable, and sometimes absolutely necessary to provide power sufficient for the movement of the requisite quantity of air, which power shall be independent of the heating apparatus. Ventilation thus produced or assisted is by some writers termed artificial, as opposed to what they call natural, ventilation, but a better term for it is forced ventilation.

The power necessary to effect this forced ventilation may be derived from the expansion of air by heat specially applied for that purpose in the outlet flue or chimney, or from fans or blowers driven by machinery, or from jets of steam or a falling stream of water. It is also theoretically possible to produce the required movement of air by cold as well as by heat; all that is essential being that there shall be a difference in temperature between the space to be ventilated and the outer air, and sufficient channels of communication between the two.

I might also include wind as a possible motive power, but enough has been said on this point in speaking of cowls, or so-called ventilators.

The great objection to it is that the power is irregular and fails just when it is most needed.

Forced ventilation by heat will usually be effected by what is commonly called an aspirating or ventilating chimney, which is a shaft or flue so constructed that the air in it can be heated without necessarily heating the room or rooms from which it is desired to withdraw the air, so that no discomfort need be caused by its use in warm weather. This heat may be applied by means of an open grate placed in the shaft, as is done in the aspirating tower for the House of Commons, and in mines, or by means of a stove, heating a sheet-metal pipe passing up the chimney, or by gas jets, or by hot-water boilers, or by the circulation of hot water or steam in coils of pipes or radiators suitably arranged in the chimney.

The open grate is a wasteful and troublesome mode of applying heat for this purpose, and would only be employed in very exceptional circumstances.

The use of gas jets would also be very expensive in this country if the amount of air to be moved was large. The necessary fixtures for the gas heating of a flue can, however, often be introduced in old buildings where any other sort of apparatus would be practically out of the question, as they take up very little space, and for the ventilation of a water closet, or similar purposes, this method gives fair results at small cost. But while the use of gas combustion as a means of forcing ventilation is, for economical reasons, not to be recommended, if this is to be the sole purpose for which the gas is consumed, it should not be forgotten that the burning of gas for illuminating purposes gives rise to heat which can often be made use of advantageously for purposes of ventilation. This is especially the case in theatres and other large assembly halls which are used at night, in which a very considerable amount of aspirating power may be obtained by suitable connection of tubes and flues with the means of illumination.

The heating of the aspirating chimney by means of a central metal pipe is a method very commonly employed to utilize the waste heat from the flues of steam boilers, etc., and gives very excellent results, as may be seen by referring to those obtained in the Barnes Hospital which are given in the preceding chapter. In private houses the kitchen chimney is sometimes used in this way as a ventilating shaft for the whole or a part of the house, the pipe from the stove or range being carried up through the centre of the chimney flue.

The application of steam heat for the purpose of accelerating the movement of air in ventilating flues is often a very convenient and satisfactory method where this source of power is available.

Professor W. P. Trowbridge, of Columbia College, published in 1882, in the *School of Mines Quarterly*, a very excellent paper on the "Determination of heating surface required in ventilating flues," with special reference to the formulæ used in calculating this for coils of steam pipe, and subsequently gave a brief article on the same subject in the *Sanitary Engineer*, which is so clear and concise that I quote it in full:

"The employment of steam pipes at the bases of ventilating flues seems to me to be worthy of more extended application than has heretofore been accorded to this method of promoting activity of circulation of air for the purposes of ventilation. It is only applicable, of course, for buildings heated by steam; but of buildings thus heated, a few only, such as hospitals, asylums, theatres, and other public buildings, are of sufficient magnitude, or are occupied by such numbers as to warrant the use of fans or blowers.

"Ordinary architectural structures must have appliances for ventilation which demand the least possible attention; or, perhaps, no attention whatever, except the opening or closing of registers. And yet it is well known that when under these circumstances spontaneous or natural ventilation is depended on, there are occasions and circumstances when partial or complete stagnation of air is inevitable. In buildings heated by steam the remedy is simple and effective. Steam, or even hot-water pipes properly arranged at the base of any vertical flue will furnish the necessary heat to produce a draught. The simple question involved is the area of heating surface demanded for a given vertical flue, and for a given quantity of air to be discharged per hour.

"In a paper first published in the *School of Mines Quarterly* (the abstract results of which were printed afterward in the *Sanitary Engineer*), I discussed the question and deduced a simple formula for the heating surface. I now venture to refer to that formula, and show how it may be used with the least amount of arithmetical calculations.

"The formula is as follows:

$$S = \frac{W\,T_a}{H\,(T_s - T_a)} \times 1500.$$

"In this formula (S) represents the number of square feet in the exterior surface of the coil or cluster of steam pipes at the base of the flue; (T_a) is the absolute temperature of the external air—that is, the common or thermometric temperature + 459.4° (or t° + 459.4°).

"(W) represents the weight of air in pounds which is discharged in one second.

"(H) represents the height of the flue, and (T_s) is the absolute temperature of the steam in the coil (*i. e.*, $t_s + 449.4°$).

"The constant 1,500 is derived from certain constants which were employed in deducing the formula, one of which was the force of gravity, another the specific heat of air, another the rate of transfer of heat to air by coils, from Mr. C. B. Richards' experiments, and another the ratio between the theoretical velocity and the actual velocity in the flue, as influenced by friction. For ordinary and the most favorable circumstances the actual velocity in the flue is best if it be established at about five feet per second, and it is for this actual velocity that the formula in its simplified form as above is adopted.

"Another formula, well known, and which is needed, is that for the weight of air discharged per second—to wit :

$$W = A \times D_c \times V.$$

"That is, the weight discharged is found by multiplying the cross section of the flue (A) by the velocity (V) and the density (D_c) of the air in the flue.

"By the calculations in my original paper, I found that the density in the flue which will result from the proportions given by this formula, will be 0.0719 pounds per cubic foot. Hence the area of flue for a given discharge, W, will be :

$$A = \frac{W}{D_c \; V} = \frac{W}{0.0719 \times 5} = \frac{W}{.3595}$$

or, $A = 3\ W$ approximately.

"That is, the cross section of the flue in square feet should be three times the weight of air discharged per second.

"An example will show the method of using these formulas for all ordinary cases.

"Suppose the air of a room 30′x 40′ and 15 feet from floor to ceiling is to be renewed four times every hour.

"The cubic contents are 30′x 40′x 15′ = 18,000 cubic feet. At the ordinary temperature and pressure, this air will weigh about $\frac{8}{100}$ of a pound per cubic foot, and the weight of air discharged per hour will be 4 x 18000 x .08 = 5,760 pounds, or 1.6 pounds per second.

"The required area or cross section will be A = 3. x 1.6 = 4.8 square feet. If, now, we suppose the steam in the coil to be low-pressure steam, for instance five pounds above the atmosphere, we shall have for its temperature, Fahr. 228°, and if we assume the exterior temperature of the air to be 60°, we shall have conditions which will apply to spring or autumn weather, and the same arrangements then determined will give better results in winter or cooler weather; with these assumptions we have:

$$S = \frac{1500 \times 1.6 \ (60 + 459.4)}{H \ (228^\circ + 459.4 - 60 + 459.4)}$$

or,
$$S = \frac{1500 \times 1.6 \ (60 + 459.4)}{H \ (228^\circ - 60^\circ)} = \frac{4.9}{H} \times 1500.$$

If the flue is fifty feet high, we shall have:

$$S = \frac{1500 \times 4.9}{50} = 30 \times 4.9 = 147 \text{ square feet.}$$

"Hence, the conditions of ventilation assumed will require an aggregate area of ventilating flue of $4\frac{8}{10}$ square feet in cross section, and 147 square feet of heating surface in the coil or cluster of pipes at the base.

"If more than one flue is employed, which would probably be desirable, in order to have a better distribution of the inflowing air (two flues for instance), then each would have an area of $2\frac{2}{10}$ square feet, and each would be heated at the base by pipes having 73½ square feet of surface.

"It may be thought that this amount of surface is excessive for the degree of ventilation assumed.

"The reply to this objection is, that if any one expects to obtain full and sufficient ventilation without expending an appropriate amount of money, both for fixtures and for fuel, such a one is mistaken.

"It might as well be expected to get water from a well without means for drawing or pumping it. The size of the bucket or pump, and the power applied, will determine the exact amount of water obtained per hour, and the cost of obtaining it.

"The sooner this law is universally recognized for ventilation, the sooner will ventilation arrangements be generally successful.

"It should be further remarked as of great importance in arranging steam pipes for heating air in its passage to flues, that the pipes should not block up the flues, but should be placed in an enlargement or chamber, so that the aggregate area through and among the pipes shall be equal to the area of the flue, or even ten per cent. greater. Moreover, the pipes or heaters should be so arranged that no air will pass without coming in contact with the heated surfaces. A baffled passage, causing the filaments of air to assume a tortuous course among the pipes, is the proper one. If the above conditions are fulfilled and properly applied there seems hardly any limit to which ventilation may be carried in steam-heated buildings."

An interesting account of the application of steam coils to produce a ventilating current is given in a description of the heating and ventilation of the library building of Columbia College, New York, contained in the *Sanitary Engineer* of June 28, 1883, from which I take, by permission, the following account and illustration :

The ventilation was arranged by the architect, Mr. Haight, in accordance with the suggestions of Professor Trowbridge.

The system of heating is by indirect radiation from surfaces heated by low-pressure steam. The radiators are arranged as shown in Figure 64.

In two of the large lecture rooms steam coils are placed at the base of the exhaust flues to induce an upward draft. "In each room there are four fresh-air inlets, each measuring 12 x 20 inches, or equivalent dimensions, less the obstructions of the register. The steam coils in these four inlets have a combined heating surface of 720 square feet. In one room all four hot-air registers are near the ceiling (ten feet from the floor to the bottom of the register ; the room is fifteen feet high), but in the other room three of them are near the floor. The latter have sheet-iron screens in front of them, eight inches larger than the register, and the same distance from the wall, to protect persons sitting in front of the register from the direct current. They are turned back to the wall on the end toward the exhaust flues, to direct the current away from the latter."

The outlets in both rooms are at the outside corners, at the floor level, into large circular flues in the corner turrets. The accompanying plan and section, Figures 65 and 66, make clear the location and size of the heating coils and the air passage through and around them.

The full size of the main outlet from the room into each turret is about 32 x 38 inches. This may be reduced as desired by a common register valve, which, however, is kept locked and under the control of the janitor. The arrangement of these coils was designed by Professor Trowbridge. They consist of three stacks of vertical 1-inch pipes, arranged in quincunx order on bases 1′x 22″, and about five feet high. The rows perpendicular to the register are separated by sheets of tin, designed to serve as secondary radiating surfaces, thus largely increasing the efficiency of the coils. Horizontal sheets also are fitted over the pipes at intervals of one foot. The pipes fill the lower back part of the passage into the flue, but a considerable unoccupied portion remains above and in front of them, as shown by the plan and section perpendicular to the register. The floor between the coils and register is tiled ; the register is fastened only by a few screws, so that it may be easily removed to clean out the dust in front of and among the coils.

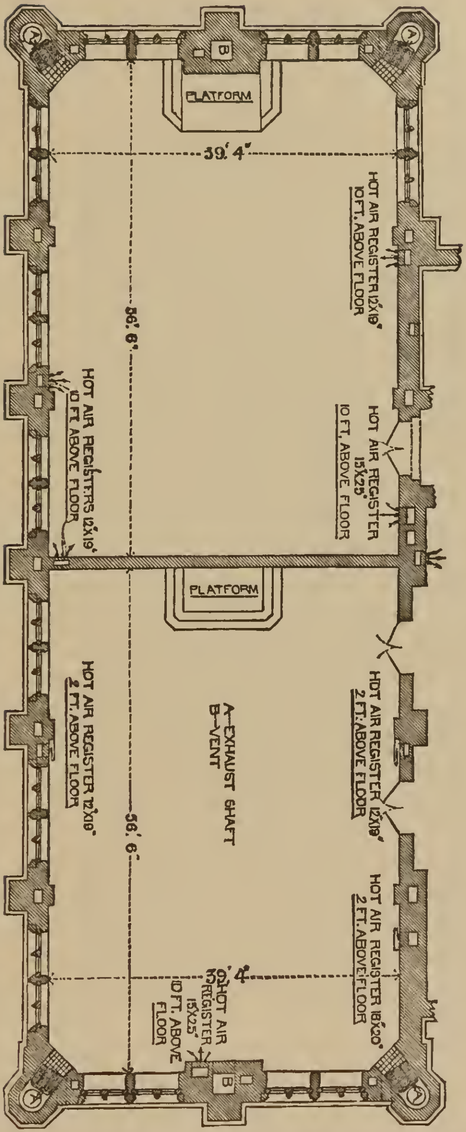


FIGURE 63.—PLAN OF LECTURE ROOM, SHOWING VENTILATING SYSTEM.

The total heating surface of the three stacks of pipe in each corner outlet is 650 square feet. The steam supplied to these pipes is not from the low-pressure system (the maximum pressure of which is ten pounds), but has a maximum pressure of fifty pounds.

The smaller circle in the turret (Figure 65) indicates the size of the flue up to this (the first) story, when it is increased to the size indicated by the larger circle. Above the larger outlet at the bottom is a smaller one directly above (ten feet above the floor), into the same large flue, designed as an auxiliary outlet for a natural circulation. By these means it is calculated to change the air in the rooms every fifteen minutes.

Extensive use of steam coils in aspirating flues is also made in the Johns Hopkins Hospital in Baltimore. In this case a certain part of the efficiency of some of the steam coils is lost, owing to the fact that they are placed high in the shafts above the entrance into the shafts of the upper air ducts, which are the ones which will do most of the work in warm weather. This loss might have been avoided by bringing these flues down to the base of the aspirating chimney, at which point the accelerating coils might then have been placed, with the result of obtaining a longer column of heated and rarified air, and a corresponding increase of power. To do this, however, would have increased the cost of construction to such an extent that it was thought better to accept the slightly increased cost of running the present apparatus for the few days during which it will be required.

The application to forced ventilation of direct mechanical power through some form of fan or blower is especially useful in theatres and assembly halls, where large numbers of people are to be gathered for a comparatively short time ; in tunnels and mines, in hospitals, and for the removal of dusts and vapors in connection with certain processes of manufacture.

As applied to theatres and halls of assembly, the fan is usually employed for the forcing of air into the room on what is called the plenum system, and instances of its application in this way will be found in the descriptions of the hall of the House of Representatives in Washington, and of the Vienna, Frankfort and New York Opera Houses given in preceding chapters.

As applied to hospital ventilation, the great utility of the fan lies in the power which it gives to rapidly flush out the wards morning and evening with large quantities of air. The effects thus produced are shown in the description of the Barnes Hospital. In some of the larger Insane Asylums of this country the propelling fan is used as a constant source of power, as for example in the New York Asylum at Utica,

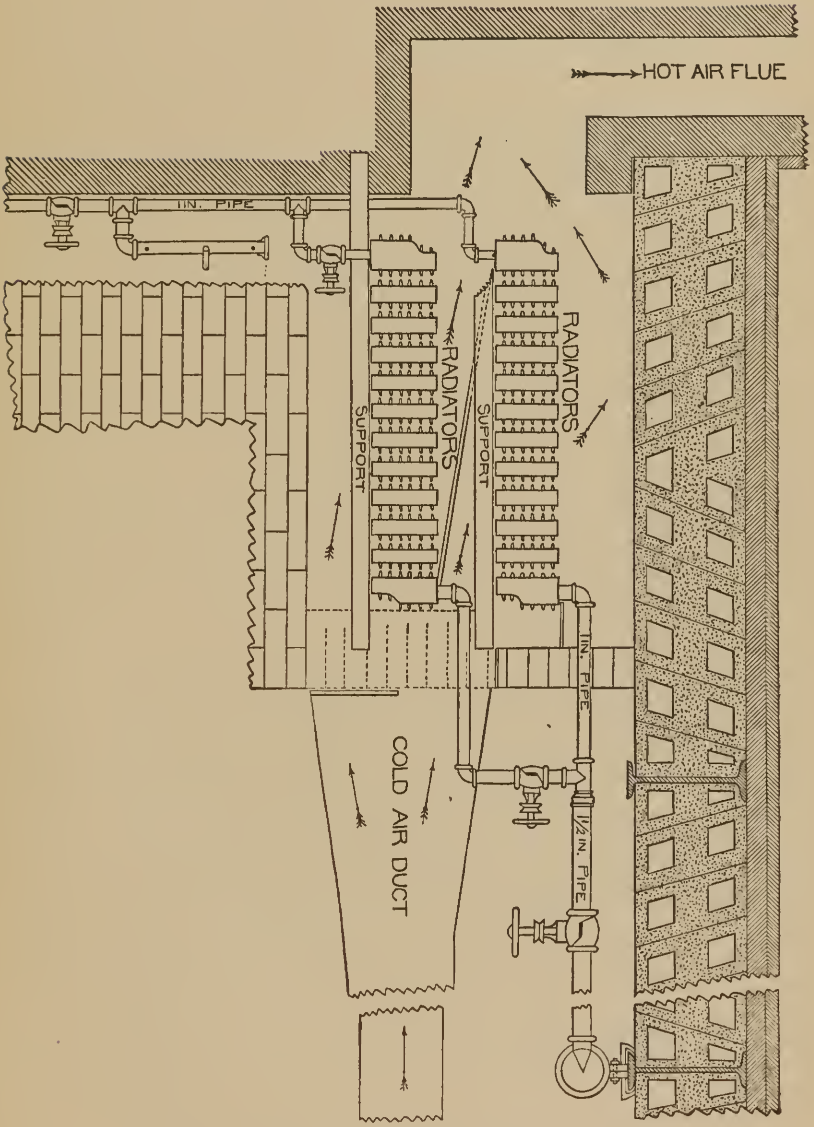


FIGURE 64.—SECTION THROUGH COIL BOX IN CELLAR.

where two fans are employed for this purpose. Each of these fans is twelve feet in diameter, having a cross-sectional area at the point of delivery of a little over forty square feet. They are run day and night, and can furnish air at the rate of 100 cubic feet per minute for each occupant.

The application of the fan or blower as an aspirator is chiefly useful to remove dusts and gases produced in a workroom, by drawing them off through hoods or funnels placed close to the machines or vessels in which these are produced, so that they are not allowed to escape and contaminate the general air supply of the room. In this way many trades which would otherwise be disagreeable or dangerous to health, may be so conducted as to be harmless, and the applications of this method are constantly increasing.

When the engineer is called on to devise a plan of ventilation for a building already constructed, in which it is impossible to construct an aspirating chimney of sufficient size to do the work, and especially where steam power is already available, the use of an aspirating fan placed in the ceiling or attic, or in the upper half of a window, etc., will often be an excellent substitute. In making such an application of the fan care should be taken to provide sufficient and properly distributed fresh-air inlets, and this caution seems necessary because I have myself seen several such aspirating fans set up without the slightest attempt being made to provide a fresh-air supply.

It does not come within the scope of this work to discuss the relative merits of various forms of fans and blowers.

The form with which I have had most experience is that of a rotary fan of comparatively large size and low speed, such as is described and illustrated in a valuable paper on this subject contributed to the Institution of Civil Engineers by Mr. Robert Briggs, and contained in their proceedings for 1869–70, to which paper I would refer those who wish to investigate this subject in detail. Such fans can move large quantities of air, but at very low pressures only, usually not exceeding that of one or two inches of water. The proper proportioning of the ducts on each side of such a fan is quite as important as the proportions of the fan itself.

The following table (page 204), from Mr. Briggs' paper above referred to, will be found convenient for such calculations :

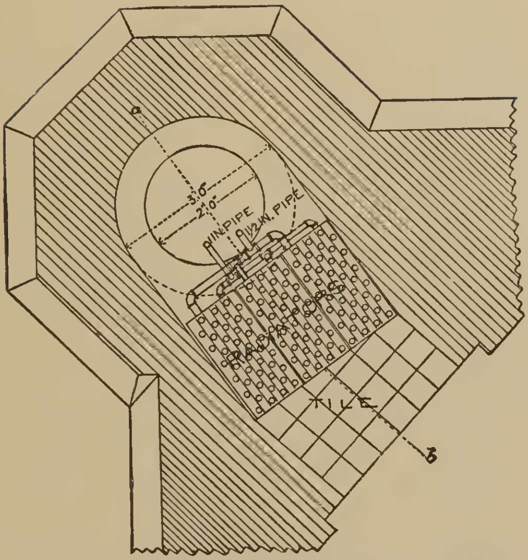


FIGURE 65.—PLAN OF COIL AND EXHAUST SHAFT IN CORNER TURRET.

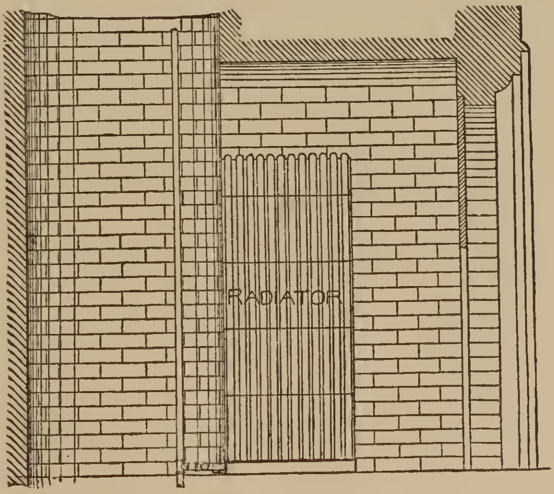


FIGURE 66.—SECTION THROUGH *a b*.

FANS TO BE USED IN THE VENTILATION OF BUILDINGS OR MINES.

Diameter of Fans.	Revolutions per Minute.	Quantity of Air delivered per Minute, corresponding to Number of Revolutions and Pressure.*	Pressure, difference between inlet and outlet of Fan corresponding to No. of Revolutions taken.*	Horse power required to deliver the quantity of air at given pressure.	Dimensions of Pulleys.**					Proper Sectional Area of Delivery Air Duct, or Passage.***
					Number of Pulleys.	Diameter of Pulleys.		Width of belt demanded.		
Ft.	Number.	Cubic Feet.	Water Col. in dec.	H. P.	No.	Ft.	In.	Ft.	In.	Square Feet, dec.
16	62½ to 125	102,500 to 205,000	0.31 to 1.23	7½ to 59	2	8	4	1	3	160.8
14	70 " 140	80,000 " 160,000	" " "	5¾ " 46	2	7	6	0	10	113.2
12	83 " 167	57,500 " 115,000	" " "	4⅛ " 33	2	6	9	0	8	90.5
10	100 " 200	40,000 " 80,000	" " "	2⅞ " 23	2	5	2	0	6	62.8
8	125 " 250	25,500 " 51,000	" " "	1⅞ " 14¾	1	4	0	0	8	40.2
7	140 " 280	20,000 " 40,000	" " "	1½ " 11½	1	3	6	0	6	28.3
6	167 " 333	14,400 " 28,800	" " "	1 " 8¼	1	2	8	0	5	22.6
5	200 " 400	10,000 " 20,000	" " "	¾ " 5¾	1	1	10	0	5	15.7
4	250 " 500	6,400 " 12,800	" " "	½ " 3¾	1	1	4	0	4	10.05

* Double the quantity of air will be delivered each minute if the resistance to discharge or suction is brought down to one-half the pressure given in the pressure column, and the pressures may be increased (the number of revolutions of the fans remaining constant), by closing partly the inlet or outlet, the quantity of air delivered being gradually diminished until the inlet or outlet be entirely shut off, when the pressures will have risen to double those stated in the table.

** The dimensions of pulleys and belt refer to the largest capacity of the fans given in the table, it being supposed that it may be desirable to range from the lowest quantity and pressure to the highest in each case.

*** The sectional area of the inlet or suction air duct or passage should exceed the areas given by 1.4 time, to allow a fan to produce its fullest effect. It has been found, when it was inconvenient to make the air ducts or channels of full sectional area to the end of a system of distribution, by enlarging them 0.025 per foot of length, so that outlets and channels, at the distance of 400 feet, were provided with double sectional areas, that the falling off of pressure was satisfactorily compensated for at the more distant outlet. It is obvious this rule will not apply to very small air passages. When the relationship of quantity and pressure corresponds to that given in the table, and it is never expected that a larger quantity will be required at a reduced pressure, the sectional area of the delivery air duct may be reduced one-half, or nearly to that extent. The sectional area given admits the passage of double the quantity of air at one-half the pressure. The frictional resistances of the sides of a duct are so considerable, that the largest duct possible should always be used, even when somewhat in excess of the dimensions given as to be desired.

Casual allusion has been made in preceding chapters to the desirability of providing, in connection with systems of air heating by indirect radiation, means by which it shall be possible to quickly control and vary within certain limits the temperature in a given room without interfering with the fresh-air supply.

In the majority of cases this can be best effected by providing switch valves in connection with the fresh-air ducts and radiators, so arranged that by turning or pulling a handle placed in the room to be warmed, an inmate of that room can compel the fresh incoming air to either pass wholly through the box or case containing the radiators, or wholly outside of it, or partly through and partly around it, so as to produce by mixture any temperature desired.

Many different ways of arranging such a switch valve can readily be devised. The following are illustrations of various forms, which will be found suggestive and which are for the most part self explanatory :

Figure 67 shows a simple and cheap form of such a valve, proposed by Messrs. Gillis & Geoghegan, of New York City.

Figure 68 shows a more satisfactory, but more expensive pattern, proposed by Mr. C. W. Newton.

Figure 69 shows the switch-valve arrangement employed in the Johns Hopkins Hospital, in Baltimore, in connection with the hot-water coils placed beneath the wards.

Figure 70 is a section of the form of radiator and switch valve recommended for hospital use by Dr. Norton Folsom, of Boston.

The "switch" or "mixing valve" shown in Figure 71 was designed by Mr. A. Mercer, of New York, for the Bridgeport Hospital.

The casings of the radiators are metal, with a by-pass at *a*. The valve consists essentially of the damper *a*, rod and crank *b*, lever *c*, and pull *d*, with the set or thumb screw *c*. The rod at *d'* may be marked to degrees or fractional parts of the opening, and in other respects the sketch shows for itself.

Figure 72 illustrates another form of "switch valve," in which all the movable parts are in the register.

It was designed by Mr. William J. Baldwin, of New York, for the architect of the Moses Taylor Hospital, about to be erected at Scranton, Pa.

The hospital is to be on the pavilion plan, the wards being a single story. The air from a blowing-fan will enter the basements under the wards, where it is to be warmed to about 60 degrees, by being passed through a large coil, which utilizes the exhaust steam from the engine which drives the fan. This converts the basements into a plenum, from which the air can be passed to supplementary steam coils on its way to

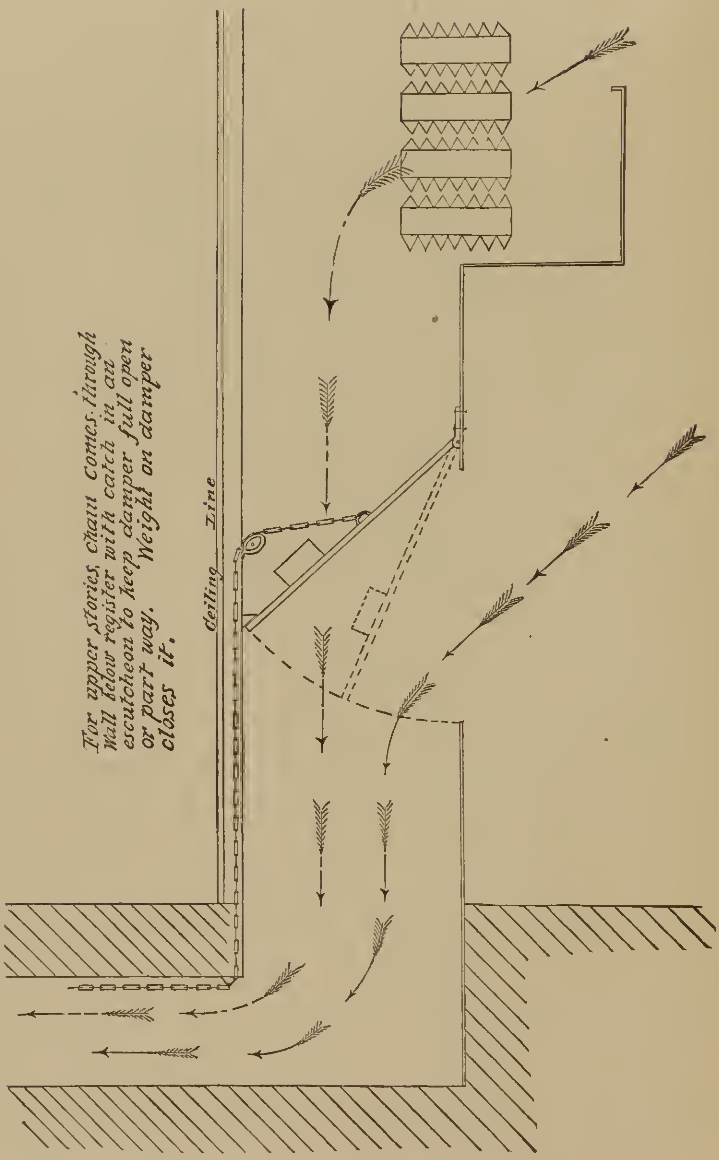


FIGURE 67.—SWITCH VALVE FOR HEATING COILS.

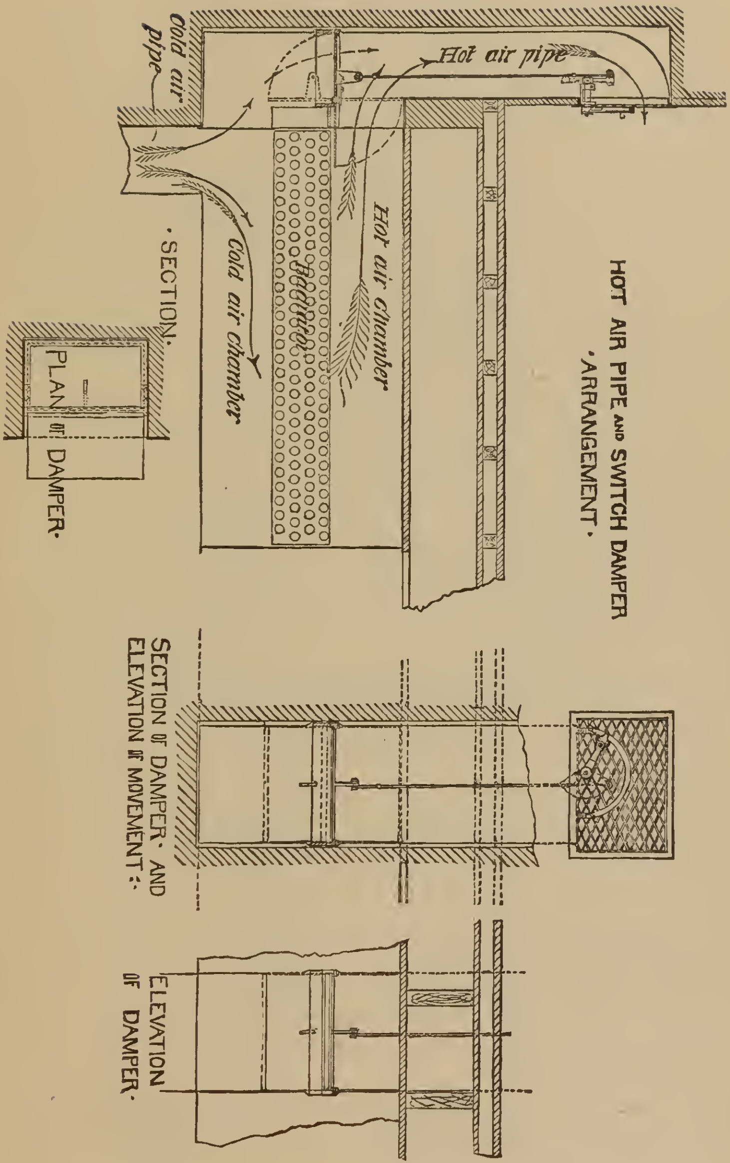


FIGURE 68.—NEWTON'S SWITCH VALVE FOR STEAM-HEATING COILS.

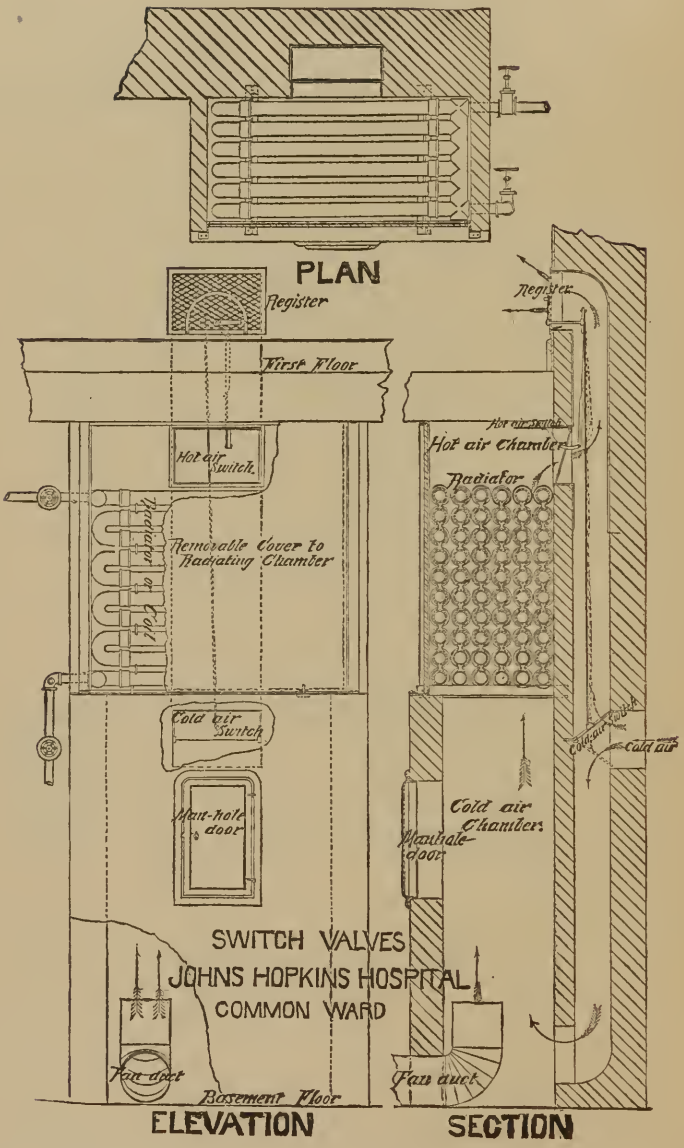


FIGURE 69.—HEATING COILS AND SWITCH VALVES.—JOHNS HOPKINS HOSPITAL.

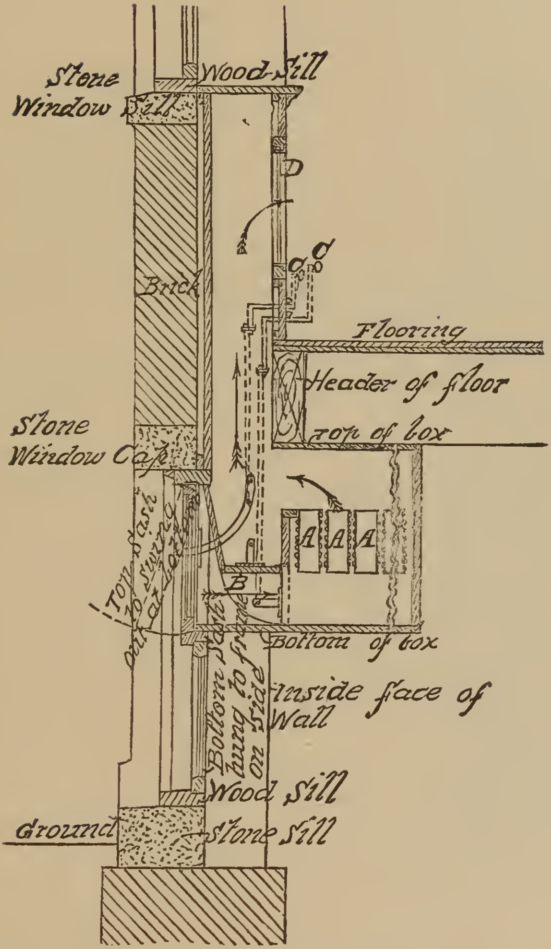


FIGURE 70.—SWITCH VALVE RECOMMENDED BY DR. N. FOLSOM.

the wards, and be made warmer, or it may be passed direct into the wards, or any mixture of the air at the two temperatures may be passed in, but by no means can the air supply be reduced. It is a circular register to all outward appearance, and is connected with a sheet-iron tube, which goes through the floor. This tube is divided its whole length by a septum, so as to form two semi-circular tubes. One of these halves is connected to the supplementary-coil chamber, and has a stopper at the bottom, while the other half is open. The register, instead of having valves in the ordinary way, has a solid semi-circular disk, which can be revolved under the fretwork by a key introduced into the slot in the middle, as shown. This semi-circular disk may be turned so as to close one or other of the semi-circular pipes, or it may

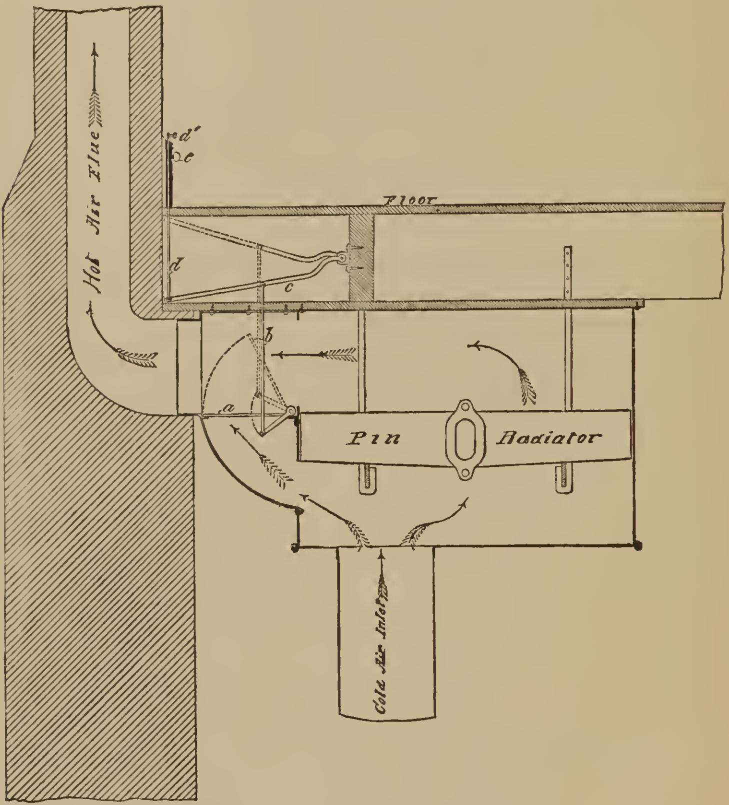


Figure 71.—DETAIL OF MIXING VALVE.

be made to cover one-half of each, so that one-quarter of the fretwork is delivering air at 60 degrees, while another quarter is delivering air at 120 degrees, or any other proportions of the two currents may be obtained by shifting the position of the semi-circular disk without reducing the volume.

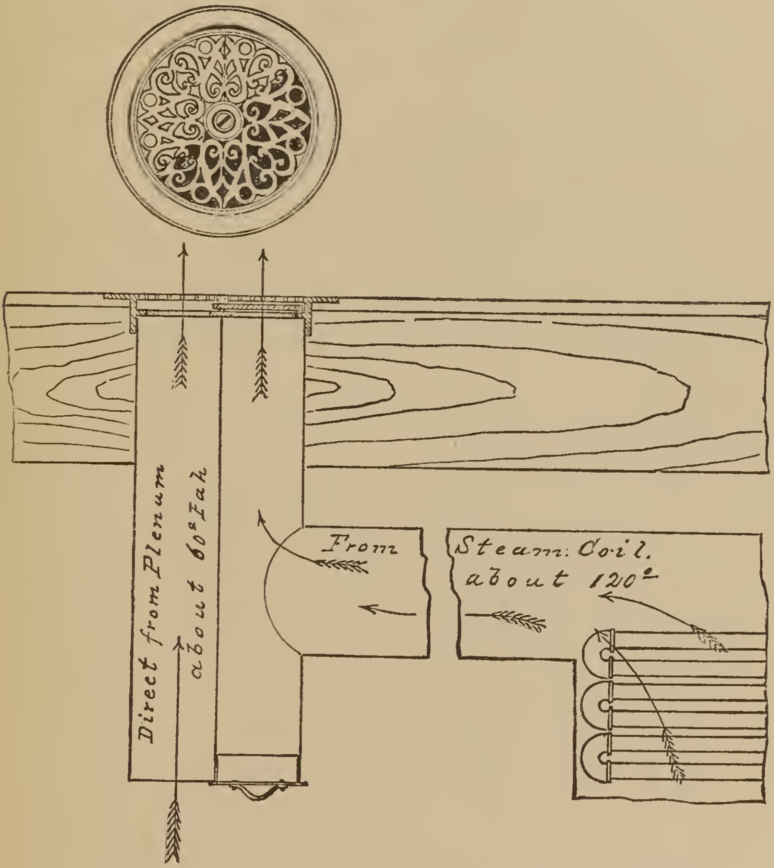


Figure 72.—PLAN AND SECTION OF MIXING REGISTER.

A modification of this register for side-wall flues has also been designed by the same person.

I consider it to be very desirable that some form of valve calculated to effect the purpose for which the above are suggested should be used much more extensively than is at present the case, and it is in this direction that the most immediate and important improvement of ventilation of dwelling-houses in this climate can be effected.

Nor should the application of this method be confined to steam and hot-water heating, seeing that it is quite as important, to say the least, in furnace-heated houses. At present, in the most costly dwellings heated by indirect radiation, the only way to promptly diminish the heat when it becomes oppressive is to close the register, and shut out the fresh air as well. It may be well, however, to warn the architect or heating engineer that to obtain good results from this device it is necessary that the occupants of the room should know how to use it, and should be willing to do so, and that to secure this willingness, it is desirable to obtain their co-operation. Such valves were provided for the radiators supplying the private parlors in a large club house in New York, and the louvres or dampers were removed from the registers to prevent persons who did not understand the apparatus from shutting off the air. The result was that some of the members insisted on having the louvres replaced in order that they might be able to turn them as they had been accustomed to do. A little educational work would not have been wasted in this instance.

Finally, it should be remembered and impressed on the managers of public institutions, that every system of heating and ventilating apparatus requires constant care as to its cleanliness, efficiency, and adjustment to the demands of the season and the hour, to produce the best results, and that the most wasteful of all expenditure is to provide an elaborate and costly apparatus, and then intrust it to the care of an ignorant or careless engineer, on the ground that he is somebody's "nephew," or is "an active politician."

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"Trap Syphonage." Report with illustration of experiments for National Board of Health. By Edw. S. Philbrick and E. W. Bowditch. Also by Col. Geo. E. Waring, Jr. Also in England by S. S. Hellyer, Esq. Interesting and valuable data.

"Coverings for Steam Pipes." Results of Some Experiments. By Mr. M. J. Bird.

Weekly "Mortality Returns" of the leading cities in the United States, with "Notes and Abstracts" from Reports of Health Officers and correspondents of the National Board of Health. These have been printed each week, beginning with issue of October 12.,

"Tin in Canned Fruits." By Prof. Albert B. Prescott.

"Negro Mortality of Memphis." By Dr. G. B. Thornton.

"Pullman Sewerage." Abstract of paper describing it. By Benezette Williams, C. E., Engineer-in-charge.

"Letters to a Young Architect on Heating and Ventilation." By Dr. J. S. Billings, Surgeon, U. S. A.

A model plan for an "Improved Tenement for Working Men in New York."

"Burning of Town Refuse at Leeds." A paper by Chas. Slagg, Assistant C. E.

"The Relative Uses of Gas and Electricity." By C. William Siemens, F. R. S.

"The Management of Heating Apparatus." By Edw. S. Philbrick, C. E.

An extract from a paper by S. S. Hellyer on the "Unsealing of Traps by Momentum"—interesting in connection with experiments made by Messrs. Philbrick and Bowditch, and Col. George E. Waring, Jr.

"Water Waste Prevention." "Regulation of Exeter Water Works." A paper by Geo. I. Deacon, M. Inst. C. E., read before Society of Arts. "Report of Boston Committee," and report of results in Cincinnati.

"The Massachusetts Law to Prevent the Adulteration of Food and Drugs."

Practical articles on "Steam Fitting and Steam Heating." By "Thermus."

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Steam Fitting and Steam Heating. By "Thermus." A series. (Illustrated.)

The Edison System of Wiring Buildings for the Electric Light. (Illustrated.)

Illustrated descriptions of the sanitary arrangements in the residence of Cornelius Vanderbilt, Esq., the Berkshire Apartment House, Home for Aged Females, and the Duncan Office Building.

The Steam Heating Companies in New York. Illustrated description of.

Full abstract, with illustrations, of the records in the *McCloskey Patent Suit* for Trap Ventilation.

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Atlantic Coast Resorts. A Report by E. W. Bowditch, C. E., to the National Board of Health.

National Board of Health, Congressional Debates on the.

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American Practice in Warming Buildings by Steam. By the late Robert Briggs, M. Inst. C. E. A paper read before the institution.

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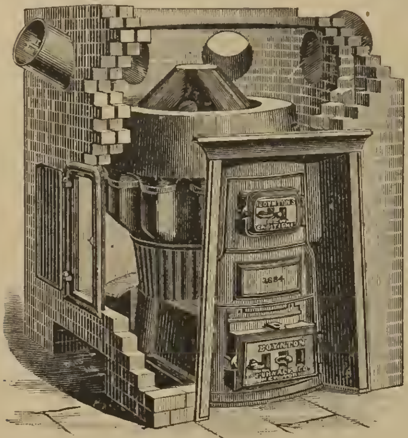

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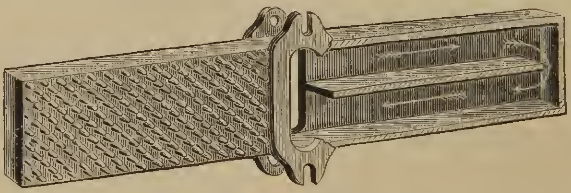

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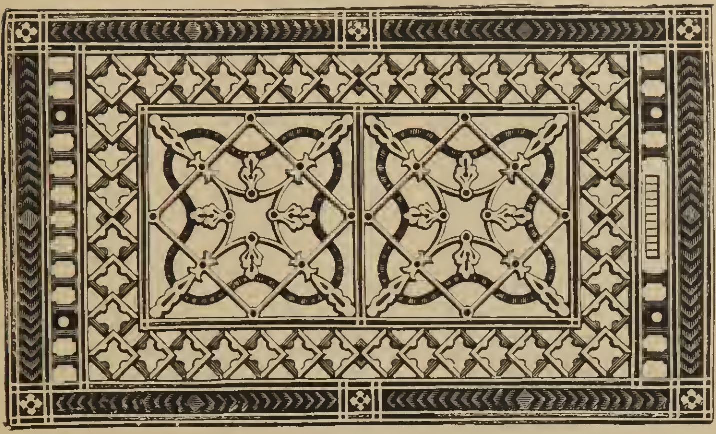

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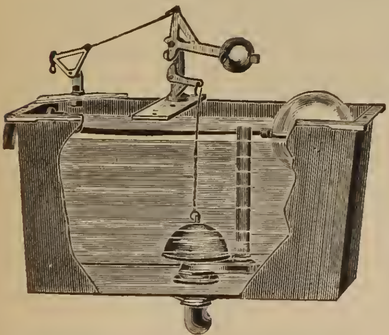

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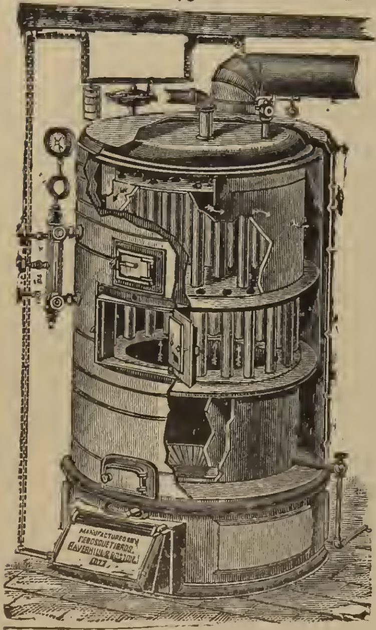
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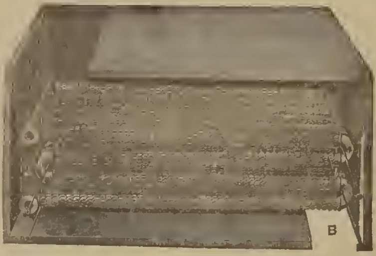
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